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THE MEASUREMENT OF SOME STANDARD WAVE-LENGTHS IN THE INFRA-RED SPECTRA OF THE ELEMENTS.

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The investigation described in the following pages was begun nearly two years ago, with the object of extending Professor Rowland's table of standard wave-lengths beyond the region which can be studied by optical and photographic means. Owing to the difficulty of devising apparatus sufficiently sensitive to measure the small differences of temperature involved, and to the fact that continuous work on the experiment has been impossible, only a few wave-lengths have so far been determined. Although their measurement has not been so exact as in the case of visible lines, the result is a much closer approximation to the truth than has hitherto been obtained.

HISTORICAL REVIEW.

Before describing the experimental methods and discussing the results, a brief sketch of the most important work which has been done previously in this field will be given.

It appears that the first evidence of the existence of radiation beyond the red of the visible solar spectrum was discovered by

Sir William Herschel,[1] who, in 1800, observed a rise of the mercury in thermometers placed in that region. He also demonstrated that this radiation obeys the same physical laws as light itself.

In 1840 Sir John Herschel[2] studied this region of the solar spectrum by exposing in it a strip of paper covered on the back with lampblack and moistened with alcohol. While moist the paper was transparent, and revealed the dark background, which would gradually disappear as the liquid evaporated. He noticed that the alcohol dried more rapidly in some places than in others, and inferred from this the existence of several absorption bands in the infra-red of the solar spectrum. Unfortunately, Herschel did not use a slit, but threw the image of the Sun directly upon his prism. Under these conditions it has been doubted whether absorption bands could be detected. Lord Rayleigh and J. W. Draper repeated the experiment, and failed to secure definite results.[3]

J. W. Draper[4] discovered in 1842 the existence of three absorption bands, and indications of a fourth, in the infra-red of a photograph of the solar spectrum taken by him on a plate of iodide of silver.

In 1846[5] Fizeau and Foucault rediscovered these bands by means of mercurial thermometers with bulbs of small diameter; and they were again observed in 1871 by Lamanski,[6] who by means of a thermopile drew an intensity curve for the entire solar spectrum up to a wave-length of about 9400 Ångström units. Mouton[7] and Desains[8] subsequently investigated the distribution of energy in the solar spectrum in the same manner.

A very different method was adopted by E. Becquerel[9] for the

[1] *Phil. Trans.* 1800.

[2] *Phil. Trans.* 1840.

[3] *Phil. Mag.* **4**, 348, 1877; *Phil. Mag.* **11**, 159, 1881.

[4] *Phil. Mag.* **24**, 456, 1842.

[5] *C. R.* **25**, 449, 1847.

[6] *Pogg. Ann.* **146**, 207, 1872.

[7] *C. R.* **87**, 298, 1879.

[8] *C. R.* **95**, 435, 1882.

[9] *C. R.* **69**, 999, 1869; **77**, 302, 1873; **83**, 249, 1876.

study of this region. He threw the spectrum formed by a carbon bisulphide prism upon a screen covered with phosphorescent material, and on the infra-red region superimposed the violet and ultra-violet spectrum formed by another prism. The phosphorescence excited by the superimposed rays would be extinguished by the infra-red radiation, while those portions of the screen on which absorption bands fell would remain faintly luminous. By the application of Cauchy's dispersion formula he then calculated the wave-lengths of these bands.

Henri Becquerel[1] repeated the experiments of his father by throwing the infra-red spectrum upon phosphorescent plates which had been exposed previously to sunlight. He noted two distinct phases in the resulting phenomena. First, especially if the previous exposure had been brief, the phosphorescence of those portions of the plate on which the radiation fell would be stimulated to greater activity, showing by contrast the spaces covered by absorption bands as dark lines, as in a positive photographic plate. After a short time the luminous energy of the over-excited parts of the plate would be exhausted, and the spectral bands would then appear bright on a dark background, as in a photographic negative. He used glass plates covered with various phosphorescent materials, such as the sulphides of calcium, barium, and strontium, and noted the important fact that there were certain regions of the spectrum characteristic of each substance in which no effect on the phosphorescence could be observed. These regions might easily be mistaken for absorption bands, and show the necessity for great caution in using this method. Becquerel examined the spectra formed by a diffraction grating in this way. From the overlapping spectrum of the second order he determined the approximate wave-lengths of bands in the solar spectrum up to about 14,000 Ångström units. He also used a prism calibrated in the infra-red by the solar bands measured as above, and from the phosphorographs of the spark and arc-spectra of various metals determined the approximate wave-lengths of some of the more prominent lines, which he

[1] *C. R.* **96**, 121, 1883.

regarded as accurate to one or two millionths of a millimeter (ten or twenty Ångström units).[1] He also observed many diffuse bands which he believed to be groups of lines.

In 1880 Abney[2] succeeded in photographing the solar spectrum to a wave-length of about 10,000 Ångström units on bromide of silver plates prepared by a special process. A few years later he photographed the spectrum formed by a Rowland concave grating, and published an extended table of infra-red wave-lengths which he regarded as accurate to about one-tenth of an Ångström unit.[3] He attempted by the same process to photograph the infra-red arc-spectra of various metals.[4] In the case of sodium he succeeded in detecting the existence of a pair of lines of wave-lengths about 8187 and 8199. He does not give the probable error of these figures. In the spectrum of calcium he discovered evidences of lines having wave-lengths between 8500 and 8600. For all the other metals tried he obtained negative results.

E. Pringsheim[5] studied the distribution of energy in the solar spectrum for some distance in the infra-red by means of a Crookes radiometer. This instrument consisted of a narrow vane supported by a bifilar suspension. The deflections produced by radiation falling on the vane were indicated by a beam of light reflected from a mirror attached to it.

A most elaborate investigation of the infra-red of the solar spectrum has been carried on for many years by Professor Langley.[6] After attempting without success to obtain sufficient sensitiveness from a thermopile, in 1879 he devised the bolometer, which indicates temperature differences by the variation of the resistance of a small strip of platinum forming one arm of a Wheatstone bridge. He has gradually improved this instrument and the galvanometer which indicates variations of the current

[1] *C. R.* **96**, 1217, 1883; **97**, 71, 1883; **99**, 374, 1884.
[2] *Phil. Trans.* 1880, p. 653.
[3] *Ibid.* 1886, p. 457.
[4] *Proc. R. S.* **32**, 443, 1881.
[5] *Wied Ann.* **18**, 32, 1883; *Phil. Mag.* **43**, 282, 1872.
[6] *Proc. Am. Acad.* **16**, 1881.

until, as he now states, it will indicate temperature differences almost as small as a millionth of a degree. He has investigated the distribution of energy in the solar spectrum up to a wave-length of nearly 60,000 Ångström units, or over a region about thirteen times as long as the visible spectrum, when expressed on the normal scale. To determine the wave-lengths of absorption bands he has used both the diffraction grating and glass and rock-salt prisms calibrated by comparison with a grating. Recently he has greatly improved the method of observation by substituting for the former tedious method of eye observation an ingenious automatic process of making the bolographs.[1] By another automatic device he translates the curves thus obtained into line spectra resembling the photographs of the visible spectrum.

A full account of Langley's recent work is given in the report for 1894 of the British Association. A note in THE ASTROPHYSICAL JOURNAL for February, 1895, briefly describes his method, and gives illustrations comparing the results obtained by Sir John Herschel, Lamanski, and Langley.

Draper[2] introduced an improvement in the phosphorographic method of investigating the spectrum. By placing sensitive plates of bromide of silver directly on the phosphorescent screen he succeeded in obtaining permanent images. Draper concluded from his experiments that it is an impossibility to secure well-defined maps of the spectrum in this manner, on account of the communication of phosphorescence from particle to particle. Lommel[3] has shown, nevertheless, that fair results may be obtained by this method. He has published some very good maps of the solar spectrum made in this way, and proposes to investigate metallic spectra by the same method. However, he did not succeed in securing any results beyond a wave-length of about 9500 Ångström units. Langley has also made some preliminary experiments in this direction.[4] Unfortunately, only the

[1] *Report of the Secretary of the Smithsonian Institution*, 1894.

[2] *Phil. Mag.* **11**, 160, 1881.

[3] *Wied. Ann.* **40**, 681, 1890.

[4] *Report of the Secretary of the Smithsonian Institution*, 1894.

strongest lines appear on such photographs, and the definition does not seem sufficiently sharp to allow very accurate measurement.

The results attained by the various methods above described have been qualitative rather than quantitative, and no systematic attempt has been made until recently to ascertain to what elements the absorption bands and lines are due, with the exception of the phosphorographic determinations made by H. Becquerel. Recently Snow[1] has investigated the prismatic spectra of the alkali metals with the bolometer for the special purpose of testing the applicability in the infra-red of certain empirical formulæ deduced by Kayser and Runge, which will be referred to later. A flint-glass prism was carefully calibrated by means of interference bands produced in the spectrum by thick glass plates. The positions of the maxima and minima of these bands were determined by a very sensitive bolometer to a wave-length of 26,680 Ångström units. The sensitiveness of the bolometer was estimated to be about $\frac{1}{130000}$ degree for one millimeter deflection on a scale three meters distant. A candle at a distance of one meter caused a deflection of 15^{cm}.

More recently Paschen[2] further improved the bolometer, reaching in some cases a sensitiveness estimated to be one-millionth of a degree for one millimeter deflection on a scale one meter distant from the mirror. Although he used a concave grating for the purpose of calibrating prisms, he seems to have made no determination of special wave-lengths.

There are two possible methods by which wave-lengths in the infra-red may be either directly or indirectly measured. One is the method of interference, of which Snow made use. Michelson[3] has shown that this method is capable of the highest precision, but as ordinarily applied the results are unsatisfactory, owing to the small distances between the maxima and minima and to the difficulty of determining their positions

[1] *Wied. Ann.* **47**, 208, 1892; *Phys. Review*, July and August, September and October, 1893.

[2] *Wied. Ann.* **48**, 273, 1893; **53**, 287, 1894.

[3] *Phil. Mag.* March, 1891, p. 256; *A. and A.* **11**, 884, 1892; *A. and A.* **12**, 556, 1893.

accurately. Snow estimated the probable error of his readings on these bands to be about 5 parts in 1000. Moreover, his bolometer strip covered from 13 to 200 Ångström units, according to its position in the spectrum, and although his observations were made with great care the error in the visible spectrum was on the average about 11, and amounted in some cases to 50 or 60 Ångström units. These errors seem unavoidable in prismatic measurements, especially in the infra-red, owing to the great condensation of that end of the spectrum.

The second and by far the most reliable method of determining wave-lengths is by means of the grating. There are three ways by which this has been done—photographic, phosphorographic and thermometric. The application of the first method to the measurement of infra-red wave-lengths of the elements has proved to be a failure. The second, though greatly improved by Lommel, gives results which are deficient in detail and in definition. At present the last method seems the most satisfactory. The bolometer has given good results in prismatic spectra, but requires great improvement in sensitiveness to give satisfactory results with a diffraction grating, owing to the feeble intensity due to the multiplicity of spectra. For this reason it does not appear that anyone has yet succeeded in detecting the existence of isolated lines in the diffraction spectrum with the bolometer. Professor Langley used a concave grating of about 163^{cm} focal length and 3610 lines per inch for the purpose of calibrating his prism, but the radiation passing through the slit, which was 2^{mm} wide, was by no means homogeneous. In one of these determinations he estimated the probable error to be from 69 to 110 Ångström units, and even with a wide slit the maximum of his galvanometer readings was only about 6^{mm}.[1] Paschen calibrated a prism by a grating similar to that above mentioned, using a very sensitive bolometer, with a strip only $0^{mm}.25$ wide. He estimated the probable error of his individual observations to be from 30 to 100 Ångström units.[2]

[1] *Report of the Mount Whitney Expedition*, p. 220.

[2] *Wied. Ann.* **53**, 287, 1894.

INSTRUMENTS AND METHODS.

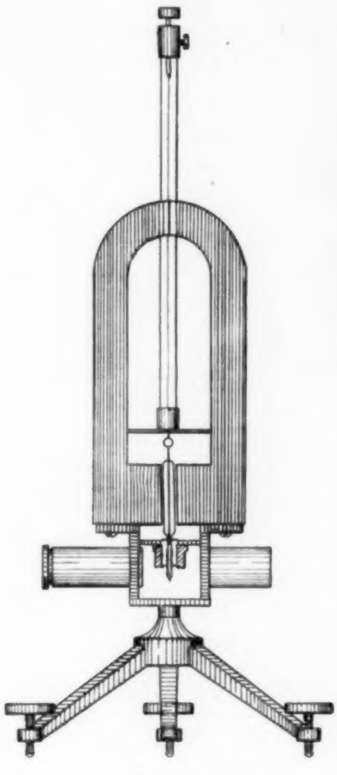
From this review it will be seen that very little has been done towards the identification of lines due to the elements in the infra-red, and practically nothing in the way of their accurate measurement, determinations having been made either by gratings of small dispersion, or by means of calibrated prisms. The latter, at best, is a very imperfect method. It was desirable, therefore, to make some measurements with a grating of high dispersion, provided that means could be devised for detecting the small quantities of heat involved. The present investigation was begun by Mr. E. S. Ferry and the writer, with a bolometer. A detailed description of this instrument and of the efforts made to secure satisfactory results from it has been published.[1] Nothing need be added to the account except the statement that further trial demonstrated conclusively that no reliable results could be obtained from the bolometer under existing conditions.

The radiomicrometer, first used by D'Arsonval and independently invented and greatly improved by Boys, commends itself by its simplicity, its freedom from external disturbances, and its great sensitiveness. It was decided to test this instrument, although it has some serious disadvantages for spectrum work. It cannot well be moved through the spectrum, and the strip upon which the radiation falls, being free to vibrate, can neither be located so definitely, nor conveniently made so narrow as the strip of a bolometer. The first difficulty might be overcome by keeping the instrument in a fixed position and moving the slit and the source of light. Since it was intended to use a grating of high dispersion, the other objections were not very serious.

A vertical section of the instrument is shown in Fig. 1. A horseshoe magnet about 25^{cm} high, 4 wide and 2 thick, with a polar gap of 11^{mm}, is screwed vertically to a brass frame supported on a tripod. This magnet was made of chilled cast iron, and has been found to retain its magnetism very well on account of the long magnetic circuit and the short distance between its

[1] *Johns Hopkins Univ. Cir.* **13**, No. 112; *A. and A.* November, 1894.

poles. At first the field was too strong, causing excessive damping of the coil, but after being somewhat weakened it proved perfectly satisfactory. By weakening the field, the effects of magnetic impurities in the wire were reduced, as these effects are proportional to the square of the intensity of the field, while the



FIGS. 1 AND 2

deflections due to the current are directly proportional to the magnetic force. The loop of wire and the thermal element were suspended between the poles of the magnet by means of a fiber supported in a long glass tube passing through a hole in the bend of the magnet. The loop was completely enclosed by plates of brass screwed to the poles of the magnet. On one side

was a narrow glass window through which the loop could be observed, and light thrown on the mirror. The thermal element was enclosed by a soft iron tube to screen its diamagnetic material from the magnetic field. The radiation fell on one junction through a tube in front of the instrument, and the element and neighboring portions of the spectrum could be viewed through an eyepiece screwed into the back.

Several months were spent in efforts to make a satisfactory coil and element. The theory of the instrument has been completely worked out by Boys.[1] It was intended to test some of his conclusions by using various sizes of wire and of loop, and different numbers of turns in the coil. However, it was soon found that one difficulty completely overshadowed all the rest; this was to secure wire perfectly free from magnetic impurities. In the preliminary experiments about twenty different specimens of copper were used, and at least seventy-five loops and elements were made and tried, but no comparable results could be obtained. Not only was it impossible to secure great sensitiveness on account of the directive force of the magnetic impurities, but the lack of uniformity of the magnetic field made it difficult to keep the spot of light on the scale. In spite of all efforts to avoid it, the center of the field was less intense than the sides; consequently the tendency of the magnetic coil was to move into the strongest part of the field, so that its plane was at right angles to the lines of force. By fastening such coils in the proper position for several hours they appeared to become permanently magnetized, and when left to themselves would retain that position for some time. There seemed to be a slow viscous change, however, caused no doubt by the shifting of the axes of the magnetized particles, which would in time carry the spot of light off the scale to one side or the other. The magnetic directive force was so great that the fiber had no control whatever over the loop. On one occasion the torsion head was turned through thirty revolutions without perceptibly disturbing the position of the coil. Finally Dr. Ames succeeded

[1] *Phil. Trans.* 1888, p. 159.

in procuring, through the kindness of R. Brent Keyser, Esq., of the Baltimore Copper Company, a piece of very pure copper wire. After being drawn to the proper size (about $0^{mm}.3$ in diameter) its surface was cleaned with chemically pure nitric acid. Coils made of this wire, while not absolutely free from magnetic effects, were found to be easily controlled by a fine silk fiber. The coil used in the final experiments consisted of a single loop of this wire 5^{cm} long and $0^{cm}.6$ wide.

Great difficulties were experienced also in making the thermal elements. Some unsatisfactory tests were made with alloys, but subsequently pure bismuth and antimony were exclusively used. The bars were usually about one centimeter long, and from one-third to one-half millimeter cross section. At first they were made by grinding lumps of the metals down to thin plates and then cutting the bars from these by a fine saw or file. Both metals are difficult to work, and at least nineteen out of twenty of the bars were broken while being made. It was found, however, that these elements could be made very easily by a method due to Noll.[1] The melted metal was sucked up in small thin-walled capillary glass tubes, which were then broken off to the desired lengths. It was difficult to remove the tube from the enclosed metal, so that in most cases it was allowed to remain as an insulation between the two bars, which were bound firmly side by side. Next they were soldered to the ends of the loop of copper wire, and their lower ends joined by a strip of thin copper about one millimeter wide and several millimeters long. A glass fiber was fastened by shellac to the copper loop, and on this was placed a small concave mirror of about one meter focus. The loop was suspended by a fiber, and the deflections were read by means of the image of the filament of an incandescent lamp reflected on a millimeter scale.

The early attempts to obtain measurable deflections in the spectrum of a high-dispersion grating were failures. Success was first attained with Professor Langley's grating, referred to above, which was kindly loaned for the purpose. As adjusted for this

[1] *Wied. Ann.* **53**, 874, 1894.

test, the strip of the radiomicrometer covered about 40 Ångström units in the spectrum. With sodium chloride burning in the arc, and the strip set over the D lines, deflections of about one millimeter were at first obtained. At Professor Rowland's suggestion a cylindrical lens was then placed with its axis parallel to the spectrum so as to shorten the images of the spectral lines and concentrate them entirely upon the strip, which was reduced to about two millimeters in length. By this means deflections of about one centimeter were obtained, but it was impossible to separate the D lines. Since it was very desirable to obtain more accurate results, attempts to use a grating of higher dispersion were resumed. The one finally used was concave, of about fourteen feet focus, and was ruled with 10,000 lines to the inch. The first spectrum was exceptionally bright, and was visible beyond the usual limit at the red end. By substituting a smaller element on the coil previously alluded to the single D lines caused deflections almost as great as those made by both lines in the spectrum formed by Professor Langley's grating. The length of the element was $1^{cm}.3$, the width of the copper strip $0^{cm}.07$, and its length $0^{cm}.2$. This loop was suspended by a silk fiber, no quartz fibers of sufficient fineness being on hand. This coil is represented in Fig. 2; e and e' are the bars, s the strip soldered between their ends, and m the mirror. The various coils made were tested by observing the deflections caused by a candle ten feet distant. With different elements tested the deflections were from one to fifteen centimeters. Comparisons of this kind are, however, no test of the sensitiveness of the element when exposed to a spectral line. As an instance of this, with the coil finally used the deflection caused by the candle was only two centimeters, yet in the spectrum it was far more sensitive than the one mentioned above from which a deflection of fifteen centimeters was obtained. The strip of the latter was twelve square millimeters in area, while that of the former was only 1.4 square millimeters. The cross section of the elements was about the same in the two cases. The size of the strip determines the quantity of heat supplied to the junction,

while the cross-section of the elements determines the amount which flows away, so that the temperature of the junction is evidently a function of the relative area and cross-section. There is no advantage, however, in having the width of the strip greater than that of the spectral lines, and when a cylindrical lens is used to shorten the lines, as in this experiment, it is advantageous to have the area of the surface which receives the radiation of exactly the same size as the image of a line. The possibility of concentrating the radiation in this manner is one great advantage which the radiomicrometer possesses over the bolometer, in using which nothing is gained by making the line shorter than the bolometer strip. The bolometer used in the beginning of this experiment gave a deflection of about three centimeters when exposed to a candle ten feet away, making it apparently more sensitive than the radiomicrometer element which gave only two centimeters deflection, but the area of the bolometer strip was eight times as great. Moreover, the cylindrical lens practically increased the sensitiveness of the radiomicrometer eight or ten times.

In addition to its greater sensitiveness, the radiomicrometer is far more reliable in its indications than the bolometer. When using the latter, nearly all the time of an experiment was spent in adjusting the resistance to balance the drift which constantly manifested itself. The necessary lightness of the galvanometer system also made it impossible to secure steadiness of the spot of light, and thermal effects in the circuit gave trouble. The radiomicrometer is perfectly free from these objections, and if it were possible to move it through the spectrum it would be an ideal instrument.

The arrangement of the spectrometer is shown in Fig. 3. An iron beam, *B*, 15 feet long, is supported on a truck at each end. These trucks roll on two rails, *A* and *C*, placed at right angles. At one end of the beam and adjusted perpendicularly to it is the concave grating *G*. At the other end is the slit *S*, beyond which is attached a box carrying an arc lamp *L*. At the intersection of the rails is the radiomicrometer *R*. The

theory of the concave grating[1] shows that under these conditions the radiomicrometer will always be in focus as the beam carrying the grating and the source of light is displaced, and that the distances through which the slit moves as measured on the rail *A* are proportional to the wave-lengths of the lines which are

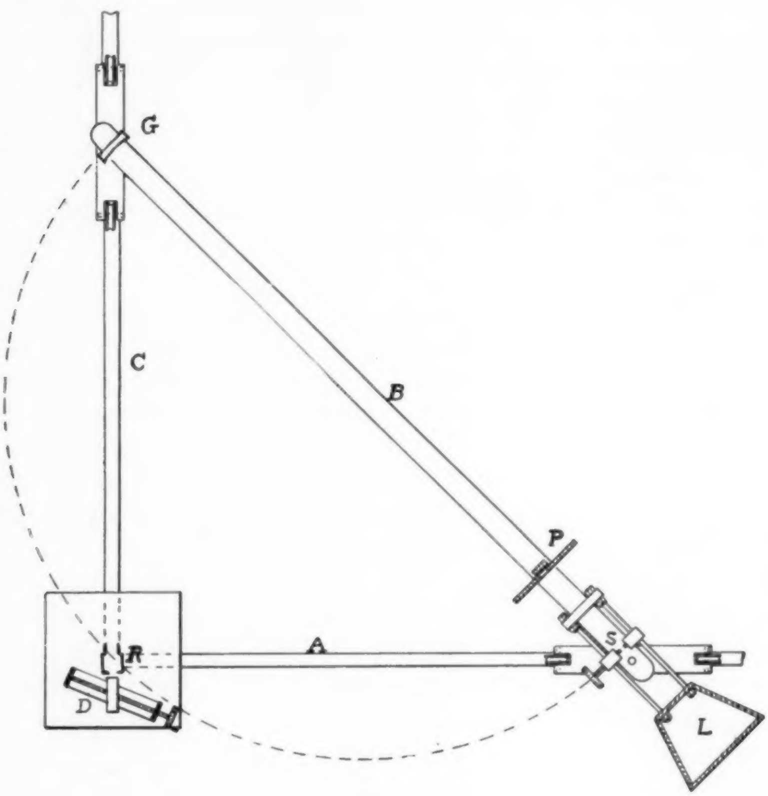


FIG. 3

observed at *R*. The wave-length of any line on which the strip is set may therefore be determined by moving *L* so as to bring known lines successively upon the strip and measuring the distances over which the slit has been moved. Since errors might

[1] ROWLAND, *Am. Jour.* **27**, 1883. Ames, *Phil. Mag.* **27**, 1889. *A. and A.* January, 1892.

arise from flexure of the beam, an attempt was made to use another plan. The eyepiece of the radiomicrometer was removed, and the opening covered with a piece of plane glass. In front of the instrument was placed a dividing engine *D*. On the carriage of the dividing engine was an eyepiece, and it was intended when the strip coincided with an invisible line to set the cross-threads of this eyepiece first on the strip and then on the neighboring known lines of the overlapping second spectrum. The spectra of a concave grating adjusted as in this case lie upon the circumference of a circle (indicated by the dotted line) having the iron beam for a diameter; hence in order to bring lines occupying different positions into the focus of the eyepiece it was necessary to place the dividing engine tangentially to this circle and at an angle with the rail, as shown in the figure. The screw of the dividing engine would, however, be tangent to the circle of spectra only for one position of the beam; consequently it was found impossible in general to bring the lines into focus, and in most of the experiments distances were measured directly on the rail by means of a steel millimeter scale and a vernier reading to tenths. The rail *A* was of such length that the first spectrum could be investigated to about wave-length 16,000.

The arc light was supplied with a current of 22 amperes, under an electromotive force of 110 volts. The carbons used were about one centimeter in diameter. Holes about $1^{mm}.5$ in diameter were drilled in both the positive and negative carbons and filled with a salt of the element under investigation. An image of the arc was thrown by a small glass lens on the slit, which was about $0^{mm}.7$ wide, so that the image of a line would about cover the radiomicrometer strip. The slit itself was mounted on a micrometer screw, so that in cases where the dividing engine was used in measuring distances to known lines the beam could be clamped, the slit moved and the deflections for successive positions plotted. From the curve drawn from these results the position of maximum intensity could be found, the slit set in that position, and distances between the strip and known lines of the second spectrum measured with the dividing

engine. Whenever readings were taken directly on the rail the slit was kept in a fixed position relative to the beam, and the readings were taken by moving the lamp and slit up and down the rail so as to bring known lines of the spectrum upon the radiomicrometer strip. Small quantities of calcium and iron were mixed with the salt to be studied in order to furnish comparison lines.

Unless the grating, the source of light, and the radiomicrometer are exactly on the vertices of a right-angled triangle, the distances on the rail will not be strictly proportional to the wave-lengths. No measurable deviation from proportionality could be observed in this case, however, and it was found that comparison lines some distance from the line which was to be measured gave quite as consistent results as those which were nearer.

At P is a screen which prevents the radiation of the arc from falling on the grating. Whenever an observation is to be taken, the slit is set in the desired position and this screen raised. If the strip is set upon a hot line, a deflection will be observed. In about ten seconds this will reach its maximum. On lowering the screen, the coil will slowly return toward its initial position, its motion being perfectly dead-beat. On account of the viscosity of the silk fiber it scarcely ever returns entirely to its zero point; for this reason only the direct deflections are usually observed.

The room in which the observations were taken is on the fourth floor of the physical laboratory. At first great difficulty was experienced from the vibrations of the building, caused by the wind, and by the passing of cable or electric cars, or of loaded wagons over the cobble stones in the street below. This was almost entirely obviated by mounting the radiomicrometer on several slabs of marble and iron laid over each other, with strips of rubber between them. Except when the wind was blowing or heavy vehicles passing, the spot of light was then almost perfectly steady, so that no trouble was found in reading deflections to $0^{mm}.1$.

There are several sources of error which must be taken into account. One millimeter on the rail A corresponds to about

four Ångström units. The strip itself covers a width of three Ångström units in the spectrum. In plotting the curve of intensity of each line there was a probable error in locating the maximum of about $0^{mm}.1$, or 0.4 of an Ångström unit. The setting on a comparison line was also somewhat uncertain, owing to the width of the slit. Errors could also be introduced from flexure of the iron beam, and from mistakes in reading the vernier. A number of settings on known lines showed that the maximum error due to these three causes was $0^{mm}.15$ or 0.6 of a unit. The radiomicrometer strip might also be accidentally displaced during a series of observations. This was guarded against by setting the cross-threads of the dividing engine eyepiece upon it, and examining its position from time to time. All these errors are as likely to occur in one direction as another, and in the course of a long series of observations would largely neutralize each other. An apparent displacement of the maximum of an intensity curve may also arise from irregular burning of the salt in the arc. This was eliminated as far as possible by running the slit first in one direction and then in the other while observing the deflections, so as to average the intensity during a considerable period. One difficulty that seemed to be without remedy was due to the use of the cylindrical lens for focusing the spectral lines on the strip. These lines have two foci — the first, which determines the definition, is that of the grating itself; the second, which determines the maximum shortening of the lines, is that of the lens. In order to secure the greatest heating effect, the strip was placed in the latter focus, by which means the definition of the lines was so impaired as to make accurate settings on comparison lines difficult.

Although the region investigated was under the second spectrum, the latter was very feeble, and no trouble was experienced on this account. At points where deflections were observed, eye observations would at once determine whether they were due to visible or invisible lines. By making observations with and without the salt under investigation in the arc, it could also be determined whether any line found in the infra-red was due to that substance.

RESULTS.

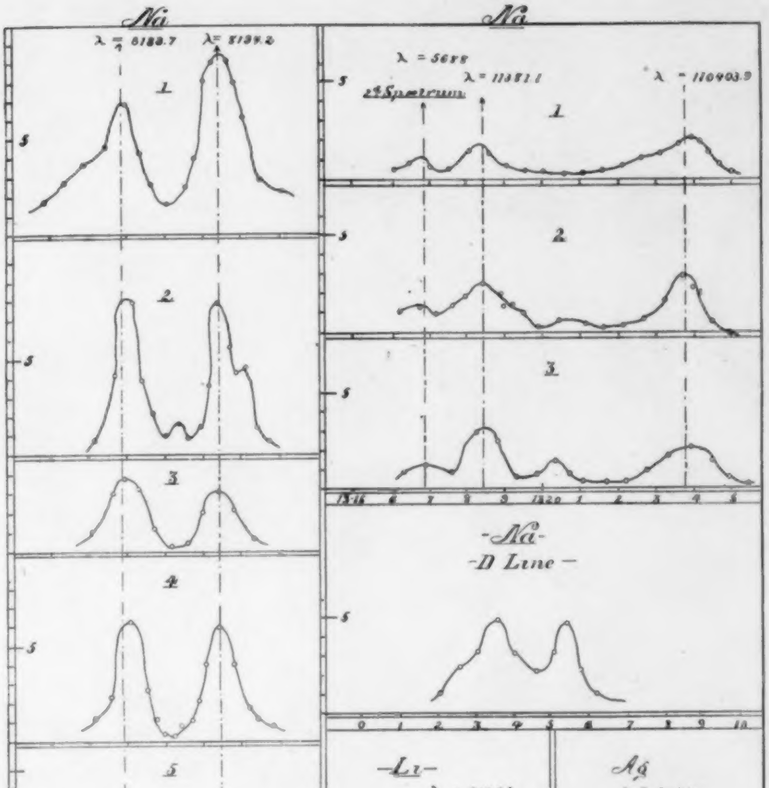
SODIUM.

Before undertaking any systematic investigation of the infra-red spectrum of any one element, it was deemed advisable to endeavor to make accurate measurements of some of the more intense lines whose positions had been approximately determined by Becquerel and by Snow. A search was first made for the sodium lines which these observers found at wave-lengths 8190 and 8180 respectively, and which had been shown by Abney to be double. The pair was soon found, and a number of observations made upon them. In order to guard against error, their curves were mapped repeatedly. The results are shown below. In order that these observations might be as absolutely unprejudiced as possible, the position of the radiomicrometer was slightly shifted before each series of observations, but in the curves here given the readings are all reduced to the same origin in order that comparisons may be more easily made. As an indication of the great labor and the time required in making these measurements it may be mentioned that the curves for this one pair of lines represent the observation of over 800 deflections, not counting those which were observed in looking for the lines.

Below is a typical set of readings, the results of which are shown in curve No. 1, Plate II. Four deflections were observed in each position of the slit, two being taken while moving the slit up the rail, the others when moving it back. The deflections are in millimeters, and the numbers at the head of each column represent the readings on the rail, in centimeters:

55.5	55.55	55.6	55.65	55.675	55.7	55.725	55.75	55.8
2	3	4	5.3	7	5	5.6	1.8	3
1.5	2.5	3.6	5	5	6.8	3	2.2	0
1.7	2	4.5	5	5.5	8.4	4.8	3.5	2
2	4	3.6	7.1	5.4	7.2	4	2.6	0.5
1.8	2.9	3.9	5.6	5.7	6.8	4.3	2.5	1.4

PLATE II



Na
Na
λ = 8183.7
λ = 8189.2
λ = 5688
λ = 11381.1
λ = 11403.9
2d Spectrum
-Na-
-D Line-
-Li-
λ = 8126.3
Ag
λ = 8274
-Ca-
λ = 7663.4
Coördinates Readings on rail and deflections in millimeters
1mm = 4.11 Ångstrom units on rail

55.85	55.875	55.9	55.925	55.95	55.975	56.0	56.05	56.1
2	3.5	8.1	8.8	9	8.4	6.2	3.2	1.8
2.8	3.5	10	9	10.5	6.8	6.3	1.8	2
2.5	4.4	7.2	8.5	7.8	8	6.8	3.1	3
3.5	5.0	7.5	10	10	8.6	6	3.8	2.6
2.7	4.1	8.2	9.1	9.3	8	6.3	3	2.6

The agreement between these curves is in general very good. There are differences in their height due to varying quantities of salt in the arc, but the positions of their maxima correspond as well as could be expected. In three of these curves (Nos. 2, 5 and 6) there are indications of a feeble line between the pair due to some impurity. A slight irregularity on the right side of one of the lines seen in curves Nos. 2, 5, 7, may be due to an iron line in the second spectrum of wave-length 4098.3, since a small quantity of iron was used in the arc to produce comparison lines. No evidence of reversal is perceptible. In fact, on account of the width of the strip, the only result of reversal would be a slight flattening of the curves. The deflections obtained from the D lines were about the same as those for this pair, indicating that they are of about equal intensity.

On one or two occasions, when a large amount of salt was in the arc, this pair of sodium lines was barely visible. They were so hazy and diffuse, however, that no eye measurements could be taken.

Below are the wave-lengths of the sodium pair as determined from the various curves. In cases where readings were taken on the rail, the wave-lengths were calculated for the first line, and to the average of these results (each of which was determined from one comparison line) was added the number of units corresponding to the distance between the maxima on the curve in order to obtain the second line. In the set of readings obtained from the dividing engine independent determinations were made

for each line. In the second set of observations only two readings on comparison lines were obtained, owing to an accidental displacement of the dividing engine. (Columns marked D were measured by the dividing engine; those marked R direct on the rail).

1 (R)	2 (D)	3 (R)	4 (D)	5 (R)	6 (R)	7 (R)
8184.19 8184.31 8182.96 8184.70 8182.53 8184.11 8183.52	8184.14 8184.52	8183.54 8183.66 8184.16 8184.24 8183.83	8184.50 8183.89 8184.44 8184.41 8183.69	8183.76 8183.27 8183.17 8183.64 8183.75	8183.71 8183.58 8184.27 8183.26 8182.53 8183.94	8182.67 8182.57 8182.55 8182.56 8183.36
8183.73	8184.33	8183.84	8184.19	8183.52	8183.55	8182.74

General average, 8183.73.

10.63		10.87	8194.15 8194.08 8194.43 8194.09 8193.17	10.44	10.44	11.69
8194.36		8194.71	8193.98	8193.96	8193.99	8194.43

General average, 8194.24.

The close agreement between these results indicates that the error of the mean can hardly be as great as one Ångström unit, and probably does not exceed 0.5.

It should be noted that Abney did not claim any great accuracy in his measurement of this pair. The nearest lines to the above given in his table for the solar spectrum are 8184.4 and 8193.4, to which must be added about 1.4 to reduce from Ångström's to Rowland's scale, giving 8182.8 and 8194.8.

Balmer showed that the wave-lengths of certain series of lines in the hydrogen spectrum could be represented with surprising accuracy by the empirical formula $\lambda = h \frac{n^2}{n^2 - 4}$, n representing the successive ordinal numbers above 2 and h a constant.[1] Later Kayser and Runge showed that in the spectra of nearly all the elements there are series of lines whose positions can be expressed by empirical formulæ of the form

$$\frac{1}{\lambda} = A + Bn^{-2} + Cn^{-4} + \ldots\ldots$$

where $\frac{1}{\lambda}$ is a number proportional to the frequency and n represents the successive ordinal numbers.[2] They have also found that in cases where series of pairs occur, as in the case of sodium, the difference of the values of $\frac{1}{\lambda}$ between the two members of any pair is a constant for that element. The average value of this difference for sodium is 172. The difference shown by the above results is 160, which is as close agreement as is found with some pairs in the visible spectrum. Kayser and Runge have predicted from their empirical formulæ the occurrence of various lines in the infra-red. They appear to have used Abney's values for the pair discovered above, reduced to Rowland's scale, for the determination of the constants of their formulæ for sodium, and have predicted the existence of another pair of wave-lengths 11481.8 and 11504.8, which perhaps correspond to a line discovered by Becquerel of wave-length 11420 and given by Snow as 11320. The neighborhood of the spectrum corresponding to these lines was explored several times without success. At last, by using large quantities of sodium chloride in the arc, they were discovered just above the sodium pair 5682 and 5688, in the second spectrum. The readings made on them were as follows:

[1] *Wied. Ann.* **25**, 80, 1885.

[2] *Abhand. d. K. Akad. d. W. Berlin*, 1888–93.

	I	II	III
	11378.26	11381.35	11381.76
	11381.72	11381.59	11382.00
	11382.43	11381.05	11381.46
	11381.50	11379.84	11380.68
	11380.50	11380.93	11381.77
	11380.88	11380.95	11381.53
Add distance, between maxima	23.20	22.57	22.60
	11404.08	11403.52	11404.13

General averages .... 11381.12 / 11403.91

The agreement of these observations is not so good as of those lower in the spectrum on account of difficulty in focusing on comparison lines. The intensity of these lines seems about one-third that of the other infra-red pair. Their difference in frequency is 176.

No absorbents were used to cut out the second spectrum in these observations. As is well known, sodium or potassium in the arc will almost eliminate the carbon spectrum, and visible lines were easily avoided. That the lines were actually due to sodium was demonstrated by the fact that no deflections were obtained unless sodium was in the arc.

.The results for sodium are compared with those of other observers below:

Becquerel	Snow	Abney	Kayser and Runge (calc.)	Lewis
8190	8180	8187	—	8183.7
—	—	8199	—	8194.2
11420	11320	—	11481.8	11381.1
—	—	—	11504.8	11403.9

LITHIUM.

Snow found a lithium line of wave-length 8110, while Kayser and Runge predicted its occurrence at about 8190. They considered, however, that under the circumstances this was a sufficiently close agreement with Snow's result. I have found

this line and made the following measurements of its wave-length:

I	II
8127.03	8125.91
8125.86	8126.03
8126.99	8126.99
8125.97	8126.43
8126.47	8125.52
8126.08	....
8126.40	8126.16

General average, 8126.3

Becquerel gives no results for lithium.

SILVER.

Becquerel gives the wave-lengths of two silver lines as 7710 and 8250, and describes them as being very intense. Kayser and Runge predict the existence of silver lines of wave-lengths 7695 and 8282. A line apparently corresponding to the last was found without difficulty. Below are the measurements:

I	II
8274.49	8273.29
8274.52	8272.99
8274.00	8274.13
8274.47	8273.97
8275.29	8273.32
8274.55	8273.54

General average, 8274.04

While searching for the other line, rather feeble indications of its existence were given by the radiomicrometer. The line was found to be faintly visible, and its wave-length was deter mined by eye observations as follows:

7687.79
7687.91
7688.44
7689.14
7688.65

7688.4

CALCIUM.

A systematic search for calcium lines in the infra-red was begun, but so far it has been unsuccessful except in the case of a line which is faintly visible. The result is an evidence of the reliability of the radiomicrometer. By means of it alone the line was found and its wave-length determined as follows:

7663.38
7663.30
7664.06
7662.60
7663.81
———
7663.43

It was subsequently found to be visible under favorable conditions, and from eye observations its wave-length was determined to be 7663.76. This is almost coincident with a strong potassium line, but since the deflections caused by it were greater than those obtained when potassium was burning in the arc, it is probably really due to calcium, and not to traces of potassium.

Becquerel observed indications of groups of calcium lines between 8580 and 8880. A preliminary survey has been made of this region, without discovering any intense lines. The curves for lithium, silver and calcium lines show no marked peculiarities. The investigation will be continued and it is hoped that other lines may shortly be discovered.

An effort was made to determine the position of several potassium lines discovered by Becquerel and Snow, but on account of their feeble intensity they could not be detected with certainty.

Several improvements in the radiomicrometer have suggested themselves during these experiments, but have not been adopted on account of lack of time. The copper wire used for the loop should be drawn through jeweled plates in order to avoid all contact with iron. By using copper which is absolutely pure, and suspending the coil by a very fine quartz fiber, there seems to be hardly any definite limit to the possible sensitiveness of this instrument. The coil should also be lighter, in order that it

may respond more quickly to heating effects, and the width of the strip should be less in order to have greater resolving power in the spectrum. In order to prevent losses by absorption, which would be very serious further in the infra-red, lenses should be dispensed with and the image of the arc thrown upon the slit by a concave mirror. The radiation should be focused upon the strip by means of a cylindrical parabolic mirror, cut away near the vertex to allow the strip to be placed at the focus. The arc and slit should also be mounted on a carriage moved by a micrometer screw, so that more accurate measurements can be taken.

My thanks are due to Professor Rowland and to Dr. Ames for their suggestions and for their continued encouragement at times when success seemed almost hopeless.

JOHNS HOPKINS UNIVERSITY,
May, 1895.

ON THE DISTRIBUTION IN LATITUDE OF SOLAR PHENOMENA OBSERVED AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE IN 1894.

By P. Tacchini.

I have obtained the following results on the distribution of the solar phenomena observed here during the year 1894:

PROMINENCES.

Latitude	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Year
90° + 80°	0.000	0.005	0.000	0.000	0.001
80 + 70	0.000	0.003	0.000	0.000	0.001
70 + 60	0.003	0.003	0.016	0.000	0.006
60 + 50	0.018	0.010	0.002	0.012	0.011
50 + 40	0.008 } 0.324	0.046 } 0.355	0.059 } 0.430	0.045 } 0.439	0.040 } 0.387
40 + 30	0.039	0.086	0.093	0.037	0.064
30 + 20	0.080	0.073	0.082	0.119	0.089
20 + 10	0.088	0.078	0.080	0.148	0.096
10 . 0	0.088	0.051	0.098	0.078	0.079
0 — 10	0.057	0.071	0.100	0.074	0.076
10 — 20	0.065	0.068	0.107	0.102	0.085
20 — 30	0.111	0.137	0.141	0.143	0.133
30 — 40	0.103	0.081	0.104	0.172	0.115
40 — 50	0.013 } 0.676	0.035 } 0.645	0.014 } 0.570	0.021 } 0.561	0.021 } 0.613
50 — 60	0.015	0.000	0.000	0.033	0.012
60 — 70	0.222	0.099	0.011	0.000	0.083
70 — 80	0.080	0.106	0.070	0.008	0.066
80 — 90	0.010	0.048	0.023	0.008	0.022

Thus the prominences have invariably been most frequent in the southern zones, a peculiarity which was also noted for the year 1893, and for the last three quarters of 1892, with the characteristic fact of a secondary maximum in the zone (—60°—70°). In the regions about the north pole the prominences have always been faint and very infrequent.

FACULÆ.

Latitude	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Year
50° + 40°	0.000	0.000	0.000	0.004	0.001
40 + 30	0.005	0.018	0.000	0.004	0.007
30 + 20	0.072 } 0.433	0.097 } 0.466	0.074 } 0.437	0.029 } 0.347	0.068 } 0.421
20 + 10	0.159	0.197	0.185	0.139	0.170
10 . 0	0.197	0.154	0.178	0.171	0.175
0 − 10	0.197	0.149	0.130	0.180	0.164
10 − 20	0.192	0.210	0.192	0.241	0.209
20 − 30	0.120 } 0.567	0.140 } 0.534	0.167 } 0.563	0.175 } 0.653	0.150 } 0.579
30 − 40	0.048	0.035	0.067	0.045	0.049
40 − 50	0.010	0.000	0.007	0.012	0.007

The faculæ, like the prominences, have been most frequent in the southern zones, but the maxima for single zones have occurred in lower latitudes.

SPOTS.

Latitude	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Year
40° + 30°	0.000	0.000	0.008	0.000	0.002
30 + 20	0.062 } 0.391	0.094 } 0.438	0.034 } 0.453	0.026 } 0.429	0.054 } 0.428
20 + 10	0.185	0.208	0.180	0.156	0.182
10 . 0	0.144	0.136	0.231	0.247	0.190
0 − 10	0.155	0.167	0.111	0.156	0.147
10 − 20	0.330 } 0.609	0.281 } 0.562	0.359 } 0.547	0.363 } 0.571	0.333 } 0.572
20 − 30	0.103	0.104	0.077	0.052	0.084
30 − 40	0.021	0.010	0.000	0.000	0.008

The spots agree with the other solar phenomena in having their greatest frequency in the zones south of the equator. As other observers must also have noted, the most beautiful spot groups have been found only in the southern hemisphere. Metallic eruptions have been extremely uncommon, but we have found indications of eruption in the southern hemisphere. It thus follows that the manifestations of solar activity were most marked in the southern hemisphere from the second quarter of 1892 to the end of 1894. This indicates that the solar rotation cannot determine the production of the phenomena in question.

R. OSSERVATORIO DEL COLLEGIO ROMANO,
March 29, 1895.

A REVIEW OF THE SPECTROSCOPIC OBSERVATIONS OF MARS.

By W. W. CAMPBELL.

MY paper on "The Spectrum of Mars"[1] has been frequently criticised; sometimes favorably, again unfavorably, but always courteously. If the paper were now to be rewritten, two small changes would be made. They are:

1. The word "aqueous" would be omitted from the concluding paragraph, which reads, "While I believe the polar caps on Mars are conclusive evidence of an atmosphere and aqueous vapor, I do not consider that they exist in sufficient quantity to be detected by the spectroscope." The vapor is probably "aqueous," but the phenomena of the caps neither prove nor disprove that it is, and so long as many observers report phenomena of that planet which do not seem to have analogues on the Earth, we are not justified in deciding, from analogy, that the caps are aqueous.

2. In preparing my paper, I computed the relative quantities of vapor existing in the Earth's atmosphere at the times when the principal European observations were made and when my own were made. There was no evidence that the early observers selected "dry" nights, whereas at Mt. Hamilton the hygrometric conditions were always consulted before observations began; and in fact those conditions determined whether the observations should be made, or delayed. To express the fact that we had very much less aqueous vapor to contend with than the European observers had, I used the term relative humidity. Professor Young kindly pointed out, in January, that I should have said absolute humidity. I at once called attention to the error in the *Observatory* for March, and am glad to refer to it again here. However, the use of an erroneous term to express the general fact does not in the least affect the observations in question, as will appear in the sequel.

[1] *Pub. A. S. P.* **6**, 228–236.

Professor Vogel does not agree with me that the large telescope of the Lick Observatory possesses considerable advantages over small telescopes for studying planetary spectra. He says that since his "telescope has a ratio of aperture to focal length of 1 : 10, it is considerably more efficient with respect to brightness than the Lick telescope."[1] So far as the two telescopes are concerned that statement is correct; the Potsdam telescope forms a focal image of Mars which is 3.7 times as bright as that formed by the Lick telescope. But I would call attention to the principle, so ably stated by Professor Keeler on several occasions, that the brightness of the spectrum depends not only upon the brightness of the image on the slit-plate, but also upon the dimensions of the various parts of the spectroscope. The question is not whether the Potsdam telescope is considerably more efficient with respect to brightness than the Lick telescope, but whether that advantage was utilized in Professor Vogel's observations of Mars' spectrum. In my opinion it was not, as the following computations will show:

The Potsdam telescope has aperture $35^{cm}.2$, ratio 1 : 10, and therefore focal length 352^{cm}. The Lick telescope has aperture $91^{cm}.4$, focal length 1763^{cm}, and ratio 1 : 19.3. The Potsdam image of Mars was 3.7 times as intense as mine, but only one-fifth the diameter of mine. His collimator and observing telescope were 20^{cm} long,[2] while mine were respectively $52^{cm}.1$ and $26^{cm}.7$. We must assume that both used the same angular width of slit. Since the linear width of my slit was 2.6 times his, and the image of Mars had five times the diameter of his, the area of slit utilized by me was 13.0 times that utilized by him; and since his image was 3.7 times as intense as mine, it follows that 3.5 times as much light entered my spectroscope as entered his. How was the light distributed in the spectrum? That depends upon the prisms and eyepieces employed. Using the same prism and eyepiece, my spectrum was 2.6 times as wide as his, 1.3

[1] THE ASTROPHYSICAL JOURNAL, 1, 206.

[2] At my request Professor Vogel kindly sent me the dimensions of his "Spectrograph IV."

times as long, and 6 per cent. brighter.[1] If he used sufficient magnifying power to render the two spectra equal in length, my spectrum was still 1.9 times the width of his, and 82 per cent. brighter. Further, the physiological advantage of the wider spectrum in this problem must not be forgotten.

Again, Professor Vogel believes "that in the endeavor to go too far into details, Mr. Campbell has always employed too high a dispersion." There are several passages in my paper which refer to that point. Let me quote one: "Now while all these [aqueous vapor] lines can be observed individually in the solar spectrum, owing to the high dispersion which can be used, they can only be observed as groups or bands in the Martian and lunar spectra on account of the faintness of those spectra and the low dispersion which must be employed." Professor Vogel's Potsdam observations were made on one night only with "Spectrograph IV" exclusively, which gives a dispersion of $8^{mm}.6$ from $H\beta$ to the mean of $H\epsilon$ and K. My "observations were made principally with a dense 60° flint prism, with magnifying powers of 13 and 7, and occasionally with 30° prism and power 13." The dispersion with the 30° prism is $2^{mm}.7$ from $H\beta$ to the mean of $H\epsilon$ and K, less than one-third that employed by him. Making allowance for my possibly higher magnifying power, the lowest dispersion used by me was hardly more than half that used by him.

Professor Vogel attaches little or no weight to the fact that the absorption bands seem no stronger at the limb (where the atmosphere is deepest) than they do at the center of the disk (where the atmosphere is thinnest); and neither do I, if the observations were made with short telescopes and under other unfavorable circumstances. My best observation on that point was made September 7, with the circumstances as follows: Mars near meridian, altitude 62°; diameter, $18''.2$; 30° prism; length of view telescope, $52^{cm}.1$; eyepiece magnifying 26 diameters; seeing V, the best known at the Observatory; dew point (at 7.00

[1] I have neglected my greater loss by telescopic absorption, and his greater loss by atmospheric absorption.

A.M.), 38°; several bands, especially α, examined for increase of absorption at limb of planet; no increase perceptible. The circumstances could hardly have been better; the apparatus was efficient for giving great width of spectrum; the planet was near the zenith; the edges of the planet were sharply defined. In my opinion the observation "greatly strengthens the view that Mars does not have an extensive atmosphere."

Likewise Professor Vogel does not agree that Thollon's maps are of special assistance in this problem. Let us consider their application at a single point, say at the band δ.[1] With low dispersion, there is a dark band in the spectra of Mars and the Moon practically in the position of the critical band δ; but I found, from observations of the solar spectrum with weak and with strong dispersions, that Thollon's maps are correct in ascribing that band almost wholly to the solar metallic lines. While there are many weak aqueous vapor lines within the limits of that band, there are also many very prominent lines of purely solar origin. In our dry summer weather, with the Sun only 10° above the horizon (when we are looking through six thicknesses of our atmosphere), the combined solar lines formed a band several times as dense as the coincident δ band formed by the vapor lines. Thollon's maps are equally advantageous in reference to the other critical bands. It is a fact that nearly all the aqueous vapor lines, with low dispersion, are hopelessly blended with much stronger solar lines. Thollon's maps are the best maps I know of for putting the observer on his guard against the superior strength of the purely solar bands.

Mr. Lewis E. Jewell has recently published[2] an interesting paper on the relation existing between the quantity of aqueous vapor in the Earth's atmosphere and the *minimum visible* of the vapor lines in the telluric spectrum. While Mr. Jewell's results undoubtedly bear upon the question of detecting vapor in Mars' atmosphere, as well as in our own atmosphere, I consider that

[1] Professor Vogel's recent observation of water vapor on Mars depends largely upon his observations of the δ band.

[2] THE ASTROPHYSICAL JOURNAL, 1, 311–317.

the method used at Mt. Hamilton has a more direct and practical bearing than that used by him. While the observations of Mars' spectrum were making, I observed the apparent solar spectrum under a great variety of circumstances. I verified Thollon's maps, in so far as the strongest vapor lines in all the principal vapor groups are concerned, by observing them with the Sun at high and at low altitudes, on very dry and on rather damp days, using a grating of 14,438 lines to the inch in the second order. Thollon's maps were, at the same time and in the same manner, compared with Rowland's photographs of the telluric regions of the spectrum. By observing the solar spectrum on numerous occasions at low altitudes and at the same altitudes that Mars was to be observed at, using the same dispersions that Mars was to be observed with, I made myself familiar with the exact locations, surroundings, intensities and relative values of the various vapor bands. It is probable that more time was spent observing the solar spectrum than in observing Mars and the Moon. I consider that to be the only suitable method of preparing for the work.

Mr. Jewell believes that my observations were made in the months when the Earth's atmosphere contains the most moisture He supports that point by publishing a table showing the average amount of vapor in the Earth's atmosphere at Baltimore for each month of the year 1893. He finds that in June, July and August there was 3.4 times as much vapor in the air (at Baltimore) as there was in the winter months December, January, February. Mr. Jewell has sustained his point so far as Baltimore is concerned. But this has very little to do with deciding when observations should be made at Mt. Hamilton, as the following table will prove. It is compiled from the 9 P.M. thermometer readings in 1894—the year when my observations were made:

	Average dry bulb	Average dew point	Vapor per cu. ft.	Minimum dew point
January	36° F.	29° F.	1.9 grains	15° F.
February	35	28	1.8	9
March	40	32	2.1	25
April	48	31	2.0	18
May	49	41	3.0	27
June	49	39	2.7	18
July	68	40	2.8	19
August	68	38	2.6	23
September	61	41	3.0	29
October	55	40	2.8	25
November	56	36	2.5	22
December	36	33	2.2	25

The last column gives the lowest recorded dew point in each month at 9 P.M. The eight days between July 18 and 25 were unusually dry, average dew point 26°, and my principal observations were made then. Other observations were secured in August, one in June and one in September. An examination of the table will show, also taking the diameter of Mars, clearness,[1] seeing, and availability of Moon into account, that my observations were made at the most favorable time of the opposition. There were nights in the summer months which could be, and were, selected for the work, such that the dew point fell as low as at any time in the opposition. I give the meteorological data for three such nights:

	Dry bulb	Wet bulb	Dew point	Vapor per cu. ft.
1894, July 19	65°.2	46°.4	25°.3	1.6 grains
" 20	68 .0	47 .3	25 .1	1.6
" 25	58 .5	41 .2	17 .5	1.2

The results for July 19 and 20, and all the monthly averages in the preceding table, are too great for this reason: the observations were made with a stationary psychrometer, but reduced by

[1] December was continuously cloudy.

means of tables made out for sling psychrometers. The psychrometer was well ventilated by wind on July 25.

Dr. Huggins' well-known 1867 observation was made on a day, February 14, when the mean daily dew point at Greenwich was 41°.1, corresponding to 3.0 grains of vapor in each cubic foot of air. Thus in February at Greenwich, at the low temperature 44°.0, there was twice as much vapor in the air as at Mt. Hamilton on the three dates in July at the temperature 64°, not to mention the lower stratum of 4000 feet which we escape.

Mr. Maunder observed the spectrum of Mars on three nights in 1877. The mean daily data for the three dates are:

	Dry bulb	Dew point	Vapor per cu. ft.
1877, Aug. 23	56°.8	45°.3	3.5 grains
Sept. 21	47 .2	41 .5	3.0
" 26	50 .9	46 .2	3.6

The air at the dates of Mr. Maunder's observations therefore contained 2.2 times as much vapor per cubic foot as our atmosphere for the three observations given above.

The meteorological data for Professor Vogel's observations are not at hand, but he has published the dry-bulb readings at noon, as well as the maximum and minimum, for each day. The mean of the noon and minimum readings will give an approximate value of the evening temperature. Assuming a relative humidity of 70 per cent., which is probably too low an estimate, we obtain:

	Dry bulb	Dew point	Vapor per cu. ft.
1873, April 2	52°	42°	3.1 grains
" 20	43	34	2.3
June 2	57	47	3.7
" 3	61	51	4.2

Thus the quantity of water vapor in the atmosphere at Bothkamp was about the same as at Greenwich in February, when Dr. Huggins observed, and in August and September, when Mr. Maunder observed.

Among the various favorable circumstances existing here for studying the spectrum of Mars I mentioned the altitude of the Observatory, but dismissed it with the comment that it "eliminates from the problem the absorptive effect of the lower 4200 feet of the Earth's atmosphere, with all its impurities." While I formed no estimate of the extent of that advantage, Mr. Jewell says it "is unquestionably an advantage, but it is much less than he [Mr. Campbell] thinks." He says that "during the warm, humid months the amount of water vapor in the air increases with the altitude to near the height of the lower clouds, and then begins to decrease." How does that apply to this problem? Evidently the instruments at sea level (where the early observations were made) indicate less moisture in the air than there really is; and our instruments, "at the height of the lower clouds," indicate more moisture than we really have. So much the worse for the early observations! But this meteorological question, at the best, can be answered in only a crude and uncertain manner. The curve of distribution of vapor varies widely, and is always uncertain. Mr. Jewell's curve may be satisfactory one week, and highly erroneous the next. If his curve is true for the warm, humid months of Baltimore, is it true for the mild, dry summer months at Mt. Hamilton? Sometimes for weeks there are no clouds above us, while the valleys below us may be filled with fog nearly every night. Without devoting more space to this uncertain subject, it seems probable that about 0.3 of the vapor in the air is below the 4000 feet level, and 0.7 above it.[1] To be on the safe side of this uncertain question, let us assume that 0.2 is below and 0.8 above the 4000 feet level. For purposes of comparison with observations made near sea level the 1.5 grains of vapor in our atmosphere on July 19, 20, 25, are equivalent to 1.2[2] grains per cubic foot. My decisive observations were made

[1] For the basis of this estimate see Dr. Hann's results from observations on mountain slopes and in balloons, in Hazen's *Meteorological Tables*, p. 53; and Langley's *Researches on Solar Heat*, pp. 182–184.

[2] This low result for the humidity at Mt. Hamilton on the three selected nights in July is in most striking contrast with the conditions prevailing at Baltimore, where the average humidity for the month of July is between seven and eight grains of vapor per cubic foot.

with Mars about 50° to 55° above the horizon, though some were made at greater and others at less altitudes. That is, I was looking through 1.3 thicknesses of the air stratum above us, or through 1.1 times the thickness of the stratum above sea level. It should also be said that most of the decisive early observations were made with Mars only from 21° to 26° above the horizon; so that the lower stratum of 4000 feet became equivalent to an equally dense and humid one 10,000 feet deep.

My paper on the spectrum of Mars scrupulously gave credit to the earlier observers,—Rutherfurd, Secchi, Janssen, Huggins, Vogel, Maunder,—by quoting the conclusions drawn by themselves from their latest observations. On the other hand I said "that some of the observations were made under circumstances extremely unfavorable, and that between the different sets of observations there was not that close agreement which one would like to see." Professor Vogel's recent paper criticises my observations very kindly, but rigorously. At the same time he refers to, includes, and accepts the results of the 1867–1877 observations, with the single criticism that his observations in 1873 and Mr. Maunder's in 1877 were made when Mars was in very unfavorable positions. I regret that he has not analyzed the old observations as rigorously as he has mine. If these observations, instead of being physical in their nature, were for the purpose of detecting variations of terrestrial latitudes, or for any kindred purpose, they would long ago have been analyzed and compared with the utmost rigor. Should we not be equally ready to discuss physical observations? Healthy growth certainly lies in that direction; and from a purely scientific and impersonal standpoint I desire to review the observations of Mars' spectrum.

The first observations appear to have been made by Rutherfurd[1] in 1862. Three nights' observations showed the solar lines $H\alpha$, D, E, *b*, $H\beta$, G, and another at about $\lambda 5330$. Rutherfurd considered "that the D line is not present," but the strong line observed by him near the place of D was undoubtedly D.

Observations were made by Drs. Huggins and Miller on

[1] *Am. Jour.* January, 1863.

November 6, 1862 and April 17, 1863. "The principal solar lines were seen, and no other strong lines were noticed." [1]

Further observations were made in August, 1864, by Drs Huggins and Miller.[2] They detected no lines in the red, orange, yellow and green portions of the spectrum, other than those of the solar spectrum, except that "in the extreme red, probably about B and *a*, two or three strong lines were seen." Their observations in the blue and violet portions of the spectrum, and their interpretation of those observations, were withdrawn[3] as erroneous, by Dr. Huggins a few years later. Since the positions of the two or three lines seen in the extreme red were not determined, and since even B and *a* exist in the apparent solar spectrum, it is evident that the preceding observations by Rutherfurd, and by Huggins and Miller, have no positive bearing upon the question of Mars' atmosphere.

We have not the dates nor the details of Secchi's observations. They were probably made between 1865 and 1872. Professor Vogel is authority for the statement that Secchi's work did not go much further than Rutherfurd's.[4]

The first observations requiring serious consideration were made in 1867 by Dr. Huggins and by M. Janssen. Those by Dr. Huggins probably precede M. Janssen's.

Two points in Dr. Huggins' interesting paper[5] bear upon the question of that planet's atmosphere:

First, on one night, "February 14, faint lines were seen on both sides of Fraunhofer's D. The lines on the more refrangible side of D were stronger than the less refrangible lines. These lines occupy positions in the spectrum apparently coincident with groups of lines which make their appearance when the Sun's

[1] *Phil. Trans.* 1864, p. 423.

[2] *Ibid.*

[3] These observations and their withdrawal are described in a most puzzling manner in Scheiner's *Die Spectralanalyse der Gestirne* — see Frost's translation, p. 198, last paragraph. Why not change "more refrangible" to "less refrangible," and omit the last seven lines of the paragraph ?

[4] *Untersuchungen über die Spectra der Planeten*, 1874, p. 21.

[5] *M. N.* 27, 179.

light traverses the lower strata of the atmosphere, and which are therefore supposed to be produced by the absorption of gases or vapors existing in our atmosphere. The lines in the spectrum of Mars probably indicate the existence of similar matter in the planet's atmosphere. . . . . That these lines were not produced by the portion of the Earth's atmosphere through which the light of Mars had passed was shown by the absence of similar lines in the spectrum of the Moon, which at the time of observation had a smaller altitude than Mars." These "lines" were observed on only one night, apparently, and it is uncertain as to exactly what part of the spectrum they belong. They probably refer to the wide band lying on both sides of D, between wave-lengths 5880 and 5905, though they may refer to the several bands lying between the wave-lengths 5880 and 5960. This observation was made with Mars in good position, and through only 2.5 times as much telluric aqueous vapor as my best observations.

The second point is this: "One strong line was satisfactorily determined by the micrometer to be situated from *Ha*, at one-fourth the distance from *Ha* to B. As a similar line is not found in this position in the solar spectrum, the line in the spectrum of Mars may be accepted as an indication of absorption by the planet, and probably by the atmosphere which surrounds it." What is the significance of this strong line? Since there is no similar line in the spectrum of our atmosphere, it indicates that Mars' atmosphere is unlike ours. But are we to grant that this strong line exists? The observation has never been confirmed. I looked for the strong line on several favorable occasions, without success. On one night in 1877, Mr. Maunder, looking through twice as much telluric atmosphere and vapor as Dr. Huggins, saw a "very faint band" midway between *Ha* and B. On one night in 1873 Professor Vogel observed a "very faint band" at about one-fourth the distance from *Ha* to B; but he observed through as much telluric atmosphere and vapor as Mr. Maunder. Dr. and Mrs. Huggins make no mention of this strong line in their 1894 observations. I think there can be no

strong line in that position, unless it is variable between wide limits.

The dates and details of M. Janssen's work have never been published. A letter[1] written by him in 1867 states that he observed Mars' spectrum from a station on Mt. Etna, and at the observatories of Paris, Marseilles and Palermo. His conclusion was, "I believe I can announce to you the presence of aqueous vapor in the atmospheres of Mars and Saturn." Although M. Janssen has recently published[2] an interesting note on the question of water vapor in Mars' atmosphere, we still have no information concerning the dates and details of his observations. To what altitude did M. Janssen ascend? What was the altitude of Mars? Did he carry with him a telescope of sufficient size for this work? Was his spectroscope efficient? What bands were observed? Were the spectra of Mars and the Moon compared under identical circumstances? The observations cannot be discussed, because we have not the data. There was an undoubted and considerable advantage arising from the observer's altitude above sea level: he probably eliminated over one-fourth of our atmosphere, and half of the aqueous vapor. But were the other conditions favorable, or unfavorable?

The most extensive early observations were made at Bothkamp in 1873 by Professor Vogel. From his observations he considered that "it is definitely settled that Mars has an atmosphere whose composition does not differ appreciably from ours; and, especially, that atmosphere must be rich in aqueous vapor." He observed bands[3] indicating atmospheric absorption (oxygen) at λ 6279 (α) and λ 6877 (B), and bands indicating aqueous vapor absorption at λ 5700–5800 (δ), λ 5920, λ 5948, λ 6487 and λ 6555, which were stronger in Mars' spectrum than in the lunar and stellar spectra.

If we except the bands at λ 5700–5800 (δ) and at λ 6555, it must be admitted that Professor Vogel selected the best bands

[1] *C. R.* **64**, 1304.

[2] In *Bull. Mens. de la Soc. Astronomique*, January, 1895.

[3] Reduced to Rowland's scale of wave-lengths.

in the spectrum for observation. If the results had been obtained under circumstances at all favorable, I would hesitate to question the conclusions reached by so able an observer. He has said that Mars was in a very unfavorable position. Even when the planet was on the observer's meridian its altitudes on the four dates were only $21^\circ.3$, $22^\circ.2$, $24^\circ.5$ and $24^\circ.5$. It is conceded by all that our own atmosphere and the vapor it contains constitute the great difficulty in the spectroscopic study of Mars' atmosphere. Now Professor Vogel observed through 2.3 times as much atmosphere and 6.4 times as much vapor as I did.

These observations, even under the best circumstances, are exceedingly delicate. If there is any difference of intensity of the critical bands in Mars' and the Moon's spectra it must be exceedingly slight. In comparing these spectra the observer ought to be able to turn immediately from Mars to the Moon, and *vice versa*, not only that he may remember the strength of the bands, but likewise the equally important strength of continuous spectrum. Professor Vogel does not tell us on what dates he observed the lunar spectrum ; but he was unable on any of the dates to turn directly from Mars near the meridian to an equally high (low) Moon. He compared Mars' spectrum with stellar spectra. Were the stars all of strictly solar type ? If not, the comparisons prove nothing. Many of the absorption bands in Mars' spectrum contain numerous strong lines of solar origin. Unless the absorption bands in the stellar spectra include the same strong solar lines, the planet's bands would necessarily appear the stronger.

Mr. Maunder observed the planet's spectrum at Greenwich on August 23, September 21 and 26, 1877. He detected the following bands:[1] λ 5640–5690 Brewster's δ; λ 5889–5903 group of lines round D; λ 6292 α; λ 6543–6579 group of lines round $H\alpha$; λ 6021 faint band ; and very faint bands at λ 6512, λ 6696, λ 6874 (B ?). The altitude of Mars when observed was only 25°. Therefore Mr. Maunder was observing through 2.4 times

[1] *M. N.* **38**, 35. The wave-lengths are reduced to Rowland's scale, and the descriptions are Maunder's.

the vertical thickness of our atmosphere, or about 2.2 times as much as I did. There was about 2.8 times as much vapor above Greenwich as there was above Mt. Hamilton. Therefore the Greenwich observations were made through 6.1 times as much telluric aqueous vapor as mine were. The spectra of Mars and the Moon were compared on the first and third dates. Only two of the bands, the groups round $H\alpha$ and D, were seen in the lunar spectrum. He writes "that round $H\alpha$ was only ⅔ the breadth of the same group in Mars, and so much fainter that it was not seen until the pointer had been set to the proper reading for it, although, when once it had been found, it was easily recognized." It must be noticed that this lunar band, only 24 tenth-meters wide, observed with a single-prism spectroscope, in the red end of the spectrum, would be a narrow band occupying exactly the position of the very strong $H\alpha$ line. Yet Mr. Maunder could not see it "until the pointer had been set to the proper reading for it." One would think the $H\alpha$ line would make the best possible pointer. In fact, I found the $H\alpha$ line a very prominent one, and on that account gave up trying to observe the very delicate vapor band in that region. Did Mr. Maunder see the $H\alpha$ line in the lunar spectrum? It would seem not.

Again, Mr. Maunder observed that the lunar "D group was decidedly narrower than in Mars." This group (band) in the two spectra was compared on only one night, September 26. He assigned it the position λ 5888–5898 in the planet's spectrum. Now the very heavy D solar lines are at λ 5890 and λ 5896; and with the low dispersion used would cover the region λ 5888–5898. I do not see how the vapor band could be satisfactorily observed under those circumstances; and it would be still more difficult to see the "decidedly narrower" group in the lunar spectrum. The difficulty can hardly be explained on the basis of errors in determining the wave-lengths; the ever present D solar lines were perfect reference points.

It must also be noticed that the band observed at λ 5640–5690 does not occupy the position of any known telluric band Brewster's well-known band δ is at about λ 5680–5800.

Dr. and Mrs. Huggins, in 1894, repeated the half of Dr. Huggins' 1867 observations which relates to the bands in the vicinity of the D lines, arriving at the same result[1] as in 1867. They do not mention having looked for the "strong line" seen by Dr. Huggins in 1867 between *Hα* and B. They strongly suspect that there is a band in the position λ 5840–5860 which does not exist in the telluric spectrum.

Professor Vogel reobserved the spectrum on one night, November 15, 1894.[2] One atmospheric band, *a*, was observed. It was conspicuous in the spectrum of Mars, difficult to see in the lunar spectrum. Three aqueous vapor bands were observed —Brewster's δ and the bands at λ 5920 and λ 5945. Band δ was very distinct in the spectrum of Mars, weak in the lunar spectrum. The other vapor bands at λ 5920 and λ 5945 were equally distinct in both spectra. Further, a bright band somewhat more refrangible than D, due to contrast beween continuous spectrum and dark lines, appeared to be stronger in the planet's spectrum than in that of the Moon.

What weight must be given to these observations? I consider that the bands λ 5920 and λ 5945 are two of the very best bands to observe in order to detect aqueous vapor,[3] in our own atmosphere at least. Yet Professor Vogel describes them as *equally distinct in both spectra!* They therefore afford no evidence of aqueous vapor on Mars. It may be said by some that they do, because the planet was 43° above the horizon, whereas the Moon was only 25°; but until it has been determined, with the same apparatus, how much the conditions must change in order to produce appreciable change in the bands, there is no basis for the claim. The other vapor band observed, Brewster's δ, seems to me to be one of the poorest tests for aqueous vapor, at least so far as our own atmosphere is concerned, because of the supe-

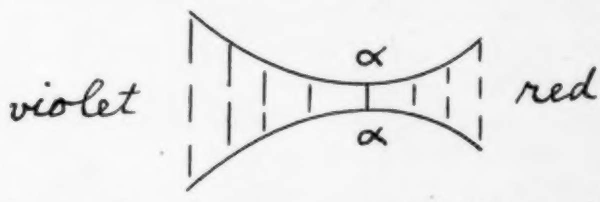
[1] THE ASTROPHYSICAL JOURNAL, **1**, 193–195.

[2] THE ASTROPHYSICAL JOURNAL, **1**, 203–209. I regret to see that Professor Vogel and Dr. Huggins have both returned to the use of the old nomenclature for designating the hydrogen lines. Is the nomenclature recently suggested by Professor Vogel to be given up?

[3] See *Pub. A. S. P.* **6**, 234.

rior strength of the purely solar lines lying within the limits of that band. If this band shows vapor on Mars, while the bands at λ 5920 and λ 5945 do not, then Mars' atmosphere must be unlike ours. Have these observations of the δ band been confirmed? Professor Vogel observed a band in 1873 in the position λ 5700–5800, and again in 1894, stronger in Mars' spectrum than in the Moon's. Mr. Maunder observed a band in Mars' spectrum at λ 5640–5690, which he called Brewster's δ, but there is no known telluric band at those wave-lengths. Dr. and Mrs. Huggins did not observe the δ band at all, but strongly suspect a band at λ 5840–5860, where there is no known telluric band. Mr. Campbell observed the δ band in both spectra to be of equal intensity, but was not sure the vapor lines exerted an appreciable influence when the bodies were more than 10° above the horizon. It would be difficult to find four results by four observers differing more widely than those do.

Professor Vogel agrees with me that it is very important, in comparing the spectra of Mars and the Moon, that the two spectra should have the same width and the same intensity. Practically, did he make his observations under those conditions? I think not. The critical bands all lie in the red, orange and yellow, but he employed a photographic telescope, corrected for the blue and violet. The planet's spectrum was not linear in the part under examination. It would have this form:



The less the dispersive power used, the steeper would be the apparent curve. Suppose the α rays were in focus: then only the α rays would enter the slit properly. The spectrum would have its full intensity at α, but would rapidly diminish in brightness as we go in either direction. It seems to me there could be only one result: the band under examination, at the brightest

point, would be intensified. If we shorten the slit so that the spectrum becomes linear, we do not remedy the matter; the intensities remain the same, and the band under examination is still at the brightest point in the spectrum. The Moon, being a large object, gives a linear spectrum, in which every part has its natural intensity, and the apparent intensities of the critical bands are not augmented. Why is it important that the two spectra be of the same brightness? To guard against physiological deception; an absorption band seen in a bright spectrum appears stronger than it would if seen in a fainter spectrum. Why is it important to give all parts of Mars' spectrum their natural intensities? To guard against physiological deception; an absorption band seen in the brightest portion of a spectrum appears stronger than if seen in the faint portions of the same spectrum. It may be possible to guard against physiological deception, but I think Professor Vogel's 1894 results, at least in part, can be explained by his having used a photographic telescope for comparing the dissimilar red ends of two spectra.

The spectrum of Mars was photographed by Dr. Huggins in 1879, by Dr. and Mrs. Huggins in 1894 and by Professor Vogel in 1894. The photographs extend from $H\beta$ far into the violet and ultra-violet. Comparisons with photographs of the solar spectrum were made by these observers. The planet's spectrum in this region showed *no* deviation *of any kind* from the solar spectrum. So far as I am informed, no attempt was made to compare, photographically, the region in which the important δ band is situated, though there are plates sensitive to the light from that region. It seems to me that we should make that the objective point of our next observations.

It is not my purpose to draw a conclusion from the observations reviewed above, other than this: many of them were made under circumstances extremely unfavorable, and between the different sets of observations there is not that close agreement which one would like to see.

MT. HAMILTON,
May 1, 1895.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. VI.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4674.648		000	4681.223		000
4674.829		0 N	4681.382		00
4674.933		0	4681.482		0000
4675.053		000	4681.646		1
4675.294	Ti	1 N	4681.781		0000 N
4675.453		000	4681.918		000 N
4675.569		00	4682.088	Ti	3
4675.785		0	4682.295	Fe?	1
4676.019		000	4682.529	Co	1
4676.188		00	4682.746	Fe?	0
4676.338		00	4682.940		000 N
4676.409		00	4683.134		000 Nd?
4676.531		00	4683.427		000 N
4676.713		00	4683.575		00 N
4676.829		000	4683.745 s	Fe	3
4677.096	Ti	00	4683.882		0000
4677.259		00	4684.001		0000
4677.415		000	4684.155		00
4677.604	Ti	00	4684.392		00 N
4677.775		0	4684.532		00 N
4677.897		000	4684.702		0000
4678.046		000	4684.774	Ce	0
4678.170		000	4684.924		000 N
4678.347 s	Cd	3 N	4685.058		000 N
4678.593		00	4685.208		0
4678.706		00	4685.452	Ca	2 N
4678.798		0000	4685.673		000 N
4679.027 s	Fe	6	4685.870		00 N
4679.249		000	4686.028		00 N
4679.409		2 N	4686.180		000
4679.594		000 N	4686.296		0000
4679.751		0000 N	4686.395 s	Ni	3
4679.995		0000	4686.544		000
4680.157		000	4686.804		00 N
4680.317	Zn	1	4686.924		00 N
4680.480		1	4687.114		00 Nd?
4680.658	Cr	1	4687.358		00
4680.745		0	4687.485		0
4680.926		00	4687.568	Fe?	2
4681.037	Cr	0	4687.712		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4687.850		00	4696.809		00
4687.981	Zr	0	4696.930		000
4688.117		000 N	4697.101		00
4688.357	Fe	2	4697.230	Cr	1
4688.554		0	4697.469		00
4688.651		000	4697.578		0
4688.862		0 N	4697.791		00
4689.236		00	4697.983		000
4689.388		000	4698.256		000 Nd?
4689.540	Cr	2	4698.451		00
4689.676	Fe?	1	4698.579	Co	0
4689.793		0000	4698.641	Cr	1
4689.935		00 N	4698.798	Cr	1
4690.149		000 N	4698.946	Ti	1
4690.317 s	Fe?	4	4699.127		00
4690.555		0	4699.309		000 N
4690.734		000	4699.511		4
4690.977	Ti	00	4699.762		00
4691.149		000 N	4699.899		00 N
4691.372		000	4700.029		000
4691.523 } s	Ti	1	4700.165		000
4691.602 }	Fe	5	4700.337		4
4691.777		1 N	4700.473	Fe?	000
4691.954		00 N	4700.614		00
4692.144		00 N	4700.795	Cr	0
4692.394		00 N	4700.989		0000 N
4692.699		00 N	4701.090		00 N
4692.829		0 N	4701.231	Fe?	1
4693.022		00 N	4701.345	Mn	00
4693.149		000 N	4701.535		1
4693.373	Co	0 N	4701.714	Ni	1
4693.513		000 N	4701.894		000
4693.852	Ti	0	4702.083		0 N
4693.964		000	4702.310		00
4694.125	Ni, Cr	1	4702.473		0
4694.298		0 N	4702.779		0
4694.478		000	4703.177 s	Mg	10
4694.632		00 N	4703.666		0000 N
4694.830		00 N d?	4703.768		00
4695.042	Fe?	1	4703.994 s	Ni	3
4695.078		00	4704.195		000
4695.331	Cr	0	4704.365		00 N d?
4695.625		0 N	4704.587		00
4695.782		00	4704.658		0
4695.926		00	4704.850		0000
4696.032		00	4704.962		0000
4696.203		00	4705.131	Fe	4
4696.444		00 N	4705.325		0000
4696.515		00	4705.425		000
4696.687		00	4705.641	Fe?	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4706.099		00	4717.494		00
4706.278		00	4717.756		0
4706.484		00	4717.891		000
4706.730	Va	0	4718.065		00
4707.249		000	4718.601	Cr	3
4707.457	Fe	5 d?	4718.766		000
4707.672		2	4719.012		000
4707.937		00	4719.407		00
4708.196	Cr	2	4719.690		0
4708.463		000 N	4719.862		000
4708.636		000 N d?	4720.035		000
4708.846		2	4720.318		00
4709.153	Ti	1	4720.571		0000
4709.271	Fe	3	4720.757		000
4709.507		000 N d?	4720.996		000
4709.680		000 N	4721.179	Fe?	2
4709.896	Mn	2	4721.310		000
4710.043		0000 N	4721.498		000
4710.252		000 N	4721.705		0000
4710.368	Ti	00	4721.927		0000
4710.471	Fe	3	4722.155		000
4710.737		000 N	4722.342 s	Zn	3
4711.197		000 N	4722.464		000
4711.665	Fe?	0	4722.646		0000
4711.804		000	4722.797	Ti	0
4712.260	Ni	0	4722.940		00
4712.433		00	4723.061		0000
4712.677		00	4723.179		000
4712.883		00	4723.294	Cr	00
4713.151		0000 N	4723.359	Ti	00
4713.361		00	4723.527		000
4713.697		0000 N	4723.628		0000
4713.989		00	4723.932		000
4714.248		0	4724.078		000
4714.381		00	4724.592		0
4714.548 } s		1	4724.718		000
4714.599 }	Ni	6	4725.033		000 N
4714.730		0000	4725.278		0000
4714.909		0000	4725.647		00
4715.089		000	4725.764		000
4715.280		0000	4726.133		00
4715.474	C?	00	4726.327	Fe?	0
4715.631		0000	4726.517		000
4715.783		000	4727.181		000
4715.946	Ni	4	4727.337	Cr	0
4716.076		000	4727.452		00
4716.319		0000 N	4727.582 } s	Fe	3
4716.686		000	4727.676 }	Mn	2
4717.015		00	4728.032		00
4717.306		0000	4728.132		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4728.349		0	4739.140		0000
4728.595		0000	4739.291	Mn	3
4728.732	Fe	4	4739.473		0000
4728.966		0000	4739.635		00
4729.207	Fe?	1	4739.839		0000 N
4729.381		0000	4740.099		0000 N
4729.460		00	4740.349	Ni	00
4729.864	Fe? Cr	1	4740.530	Fe?	1
4730.042		0000	4740.668		0
4730.212		2	4741.131		1
4730.583		000	4741.260	Fe?	1
4730.897	Cr	1	4741.538		0000
4731.177		0	4741.718	Fe	3
4731.356	Ti	000	4741.979		0000
4731.466		0000	4742.125		0000
4731.651	Fe?	4	4742.307		000
4731.841		0000	4742.482		00
4731.984	Ni	1	4742.730		00
4732.228		000	4742.979	Ti	1
4732.353		000	4743.121		000
4732.501		000	4743.289		000
4732.640	Ni	1	4743.481		0000
4732.995		000	4743.674		0000
4733.126		0000	4744.008		000
4733.400		000	4744.301		0000 N
4733.604	Ti	00	4744.573	Fe?	3
4733.779	Fe	4	4744.826		000
4733.936		0000	4745.020		0000
4734.169		000	4745.131		000
4734.283	Fe?	1	4745.325		00
4734.361		0000	4745.500	Cr	00
4734.612		000	4745.890		0000
4734.763		00	4745.992	Fe	4
4734.847		0000	4746.144		0000
4735.019		000	4746.305		000
4735.181		0000	4746.457		00
4735.492		000	4747.469		0000
4735.625		000	4747.868		000
4735.843		000	4748.015		0000
4736.031	Fe	3	4748.167	Na?	000
4736.210		000	4748.325	Fe?	4
4736.411		0000	4748.552		0000
4736.677		000	4748.734		0000
4736.963	Fe	6	4748.922		000
4737.145		000	4749.443		0000 N
4737.297		0000 N	4749.849	Co	0 Nd?
4737.540	Cr	2	4750.139	Fe?	1
4737.817	Fe?	1	4751.279		0
4737.945		0000	4751.548		0000
4738.522		0000 N d?	4751.738		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4752.012	Na?	00	4765.652		2
4752.125		0000	4765.851		0000
4752.289	Ni	2	4766.050	Mn	3
4752.471		0000	4766.621	Mn	4
4752.613	Ni	3	4766.827	Cr	000
4753.087		000	4766.966		00
4753.560		0000	4767.066		000
4754.225 s	Mn	7	4767.339	Fe?	0000
4754.549	Co	00	4767.471		0000
4754.949	Ni	1	4768.049	Cr	00
4755.342		00	4768.276	Co	000
4755.463		000	4768.519		3
4755.714		0000	4768.595	Fe	2
4755.889		00	4768.891		0
4756.019		000	4769.030		0000
4756.300	Cr	2	4769.222		0000
4756.552		000	4769.991	Ti	00 N
4756.705	Ni	3	4770.188		000
4756.913		0000	4770.881		000 Nd?
4757.213		0000	4771.279	Ti-Co	00
4757.509		000	4771.478		0000
4757.771	Fe	2	4771.664		3
4758.042		000 N d?	4771.903	Fe	2
4758.308	Ti	1	4772.086		0000
4758.615		000	4772.359		0000
4758.918		00	4772.511		000
4759.107		00 N	4772.814		0000
4759.463	Ti	2	4773.007	Fe	4
4759.716		0000	4773.209		0000
4759.858		0000	4773.333		000
4759.959		0000	4773.471		0000
4760.113		000	4773.605		00
4760.261		00	4773.715		0000
4760.405		0000	4773.900		0000
4760.935		000	4774.153		000
4761.294		00 N	4774.728		0000
4761.439		000 N	4775.330		000
4761.718	Mn	3	4775.690		0000 N
4761.899		0000	4776.072		000
4762.567	Mn	5	4776.259	Fe	00
4762.820	Ni	1	4776.546	Co	0 d?
4762.969		0	4776.678		000
4764.108	Ti-Ni	4 d	4777.370		0000
4764.282		0000	4777.780		000
4764.479	Cr	00	4777.916		000
4764.720		0	4778.441	Ti	00
4764.839		0000	4778.767		0000
4764.945		000	4779.634	Fe	1
4765.183		000	4780.169	Co	2
4765.314		0000	4780.640		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4781.007		000	4796.852		0000 N
4781.201		0000	4797.090	V	000
4781.639		000 N d?	4797.230		000
4781.913		00	4797.352		000
4782.256		000	4797.544		0000
4782.467		0000	4797.813		0000
4782.998		000	4797.908		0000
4783.169		00	4798.169		0000
4783.613 s	Mn	6	4798.293	Ti	000
4784.048		000	4798.453	Fe	1
4784.189		0	4798.724		1
4784.898		0000	4798.921		0
4785.256		0000	4799.255		0000
4785.872		000	4799.437		0000
4786.145	Fe?	0	4799.598	Fe	1
4786.309		0000	4799.771		0000
4786.472	Ni	0	4799.984	Ti	1
4786.727	Ni	3	4800.080	Cd	00
4787.003	Fe	2	4800.322		000
4787.289		0000	4800.505		0000
4787.694		0000	4800.728		0000
4788.018	Fe?	1	4800.842	Ni-Fe	2
4788.403		0000	4801.027		0000
4788.952	Fe	3	4801.213	Cr	1
4789.122		0000	4801.421		0000Nd?
4789.324		000	4801.806		000
4789.528	Cr	2	4802.100		0000
4789.638		0000	4802.709		00
4789.849	Fe	3	4802.879		0000
4790.522	Cr	00	4803.072	Fe	2
4790.755		000	4803.233		0000
4790.937		000	4803.871		0000
4791.157		00	4804.232		000
4791.329		0	4804.706	Co?	0
4791.439	Fe?	1	4804.833		000
4791.787		0000	4805.035		0000
4792.393		0000	4805.191 } s		0
4792.500		00	4805.285 }		3
4792.702	Ti-Cr	2	4805.476		0000
4793.045	Co	1	4805.606	Ti	0
4793.635		0000	4806.437		000
4793.927		0000	4806.523		000
4794.165		000	4806.801		0000
4794.549		00	4806.984		0000
4794.850		0000	4807.179	Ni	2
4795.024		0000	4807.411		000
4796.041		000	4807.725	Cr	000
4796.228		0000	4807.900	Fe	1
4796.373	Cr-Ti	00	4808.340		0
4796.551		0000	4808.733	Ti	00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4808.868	Fe	0	4821.667		000
4809.062		00	4821.788		0000
4809.332		00	4822.521		000
4809.455		000	4822.752		000
4809.661		0000	4822.857		000
4809.803		0000	4823.003		0000
4810.124		00	4823.145		0000
4810.724 s	Zn	3	4823.267		0000
4810.922		000	4823.489		000
4811.235	Ti	00	4823.697 s	Mn	5
4811.542		000	4824.077		000 N
4812.179	Ni	00	4824.325 s	Fe	3
4812.427	Ti	0000	4824.502		0000
4812.538		0	4824.613		000
4813.081		000	4824.775		0000
4813.187		0000	4825.018		0000
4813.300		0	4825.145		000
4813.447		0000	4825.530		00
4813.661	Co	1	4825.666	Ti	000
4813.908		0000 N	4825.787		0000
4814.166		000 N	4825.907		000
4814.451		000	4826.554		0000
4814.559		000	4827.029		000 N
4814.776		00	4827.458		0000
4815.057		0000	4827.637	V	000
4815.239		0000	4827.804	Ti	00
4815.412		000	4828.513		0000 N
4815.492		0000	4828.899		0000
4815.674		0000	4829.042		0000
4815.820		0000	4829.214	Ni	3
4816.013		0000	4829.351		0000
4816.119		00	4829.492		0000
4816.319		000	4829.551	Cr	2
4816.606		0000 d?	4829.878		0000
4816.865		0000	4830.486		0000
4817.148		0000	4830.707		0000
4817.559		0000 N	4831.365	Ni	3
4817.820		0000	4831.578		000
4817.988	Ni? Fe?	2	4831.831	V	00
4818.217		000	4832.099		0000
4818.428		0000	4832.233		0000
4818.569		0000	4832.460		0000
4818.843		0000 N	4832.615	V	00
4819.205		0000	4832.731		0000
4819.369		0000	4832.905	Fe	3
4819.525		0000	4833.075		0000
4819.830		0000	4833.378		000
4820.593	Ti	1	4833.559		0000
4821.189		000	4833.761		0000
4821.309		0	4834.019		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4834.164		0000	4843.880		0000
4834.356		0000	4844.032		0000
4834.538		0000	4844.210	Fe	1
4834.695	Fe	1	4844.408	Mn	0000
4834.796		000	4844.498		000
4834.998		000	4844.688		00
4835.276		0000	4844.887		0000
4835.471		000	4845.061		000
4835.729		0000	4845.363		000
4835.888		0000	4845.533		000
4836.059	Fe	2	4845.692		0000
4836.187		0000	4845.843	Fe	1
4836.313	Ti	0000	4845.991		000
4836.423		0	4846.187		0000 N
4836.649		0000	4846.342		0000 N
4836.858		0000	4846.571		000 N d
4837.044	Cr	00	4846 898		0000
4837.230		0000	4847.375		0000
4837.382		0000	4847.497	Ca	0
4837.584		0000	4847.634		0000
4837.850		0000	4847.809		0000
4838.009		0000	4847.924		000
4838.130		0000	4848.110		0000
4838.277		00	4848.273		000
4838.404		0000	4848.438		2
4838.526		0000	4848.605	Ti	0000
4838.699		2	4848.656		000
4838.837[1]	Fe, Ni	1	4848.836		0000
4839.012		0000	4849.078	Fe	1
4839.305		0000 N	4849.261		0000
4839.548		0000	4849.357		0
4839.734	Fe	3	4849.526		0000
4839.973		0000	4849.738		0000
4840.075		000	4849.845	Cr	00
4840.193		0000	4850.063		0000
4840.449	Co	2	4850.386		000
4840.501	Fe	3	4850.934		0000
4841.074	Ti	3	4851.126		0000
4841.683		0000	4851.321		0000
4841.859		0000	4851.508		0000
4842.977		0	4851.689	Ca, V	1
4842.159		000	4851.864		0000 N
4842.395		0000	4852.055		000
4842.774		0000	4852.208		00
4842.918		0000	4852.743		2
4842.980	Fe	1	4852.927		0000 N
4843.123		000	4853.221		0000 N
4843.336	Fe	3	4853.467		000
4843.554		000	4853.726		0000
4843.690		00	4853.960		00

[1] Is this Si ?

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4854.060		0000	4866.465	Ni	2
4854.346		000	4866.930		0000
4854.535		0000	4867.071		0000
4854.809		000	4867.724		00
4855.059	Fe	1	4867.822		0000
4855.348		000	4868.056	Co	1
4855.416		0000	4868.296		0000
4855.600	Ni	3	4868.451	Ti	0
4855.740		0000	4868.599		00 d ?
4855.859	Fe	2	4868.991		0000
4856.084		0000	4869.119		0000
4856.203	Ti	1	4869.330		0000
4856.380		00	4869.652	Fe?	0
4856.580		0000	4870.230		00
4857.082		000	4870.323	Ti	1
4857.280		000	4870.603		000 N
4857.579	Ni	1	4870.829		0000 N
4857.744		0000	4870.996	Ni, Cr	3
4857.967		000 N	4871.232		000
4858.323		0000	4871.404		0000
4858.443		000	4871.512	Fe	5
4858.508		0000	4871.867		0000 N
4858.675		0000	4872.112		1
4858.968		0000	4872.332	Fe	4
4859.221		000	4872.692		0000 N
4859.316	Fe?	0	4872.885		0000
4859.485		0000	4873.092		000
4859.667		0000	4873.276		0000
4859.928 s	Fe	4	4873.440		0
4860.203		0000	4873.630	Ni	2
4860.401		00	4873.792		0000
4861.173		0	4873.935		00
4861.527 s F	H	[1] 30	4874.055		0000
4862.029	Cr	0	4874.196		0
4862.134		00	4874.379		0000
4862.368		000	4874.544		0
4862.550		0000	4874.693		0000
4862.732		000	4874.834		000
4862.783		0	4874.976	Ni	0
4863.277		000	4875.277		0000
4863.431		0000	4875.215		0
4863.649		000	4875.381		0000
4863.833	Fe	2	4875.522		0000
4863.961		0000	4875.671	V	1
4864.160		0	4875.921		0000
4864.362		0000	4876.060	Fe	2
4864.505		1	4876.275		0000
4864.726		0000	4876.384		000
4864.919	V	0	4876.586		1
4865.798		1	4876.666		00

[1] Width of F is 0.750.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4876.855		000	4888.822	Fe	2
4877.772		0	4889.011		0000
4878.033		000 N	4889.187	Fe?	3
4878.313	Ca	3	4889.294	Fe	2
4878.407	Fe	4	4889.830		0000
4878.690		0000	4890.397		0000
4878.902		000	4890.620		0000
4879.331		000	4890.948 s	Fe	6
4879.701		0000	4891.223		000
4879.883		0000	4891.332	Co	000
4880.225		000	4891.683	Fe	8
4880.501		0000	4892.047		000
4880.715		000	4892.138		0000
4881.128	Ti	000	4893.030	Fe	1
4881.448		0000	4893.228		000
4881.739	V	1 N	4893.434		0000
4881.904	Fe	2	4893.606		000
4882.129		0000	4893.751		0000
4882.336	Fe	3	4893.886		000
4882.518	Ti	000	4893.997		00
4882.670		000	4894.141		0000
4882.891		000	4894.551		000 N
4883.091		0000 N	4894.743		00
4883.313		0000 N	4894.977		0000
4883.651		000 N	4895.214		0000
4883.867	Yt earth	2	4895.841		000 N
4884.084		000	4896.625	Fe	1
4884.242	Mn	000	4896.763		000
4884.779		0	4897.379		0000
4884.984		000	4897.652		000
4885.124		000	4898.652		0000
4885.264	Ti	2	4898.798		0000
4885.418		0000	4899.702		000 Nd?
4885.620	Fe	3	4899.917		0000
4885.802		0000	4900.095 s	Ti La	2
4885.955	Cr	0	4900.301 s	Y?	2
4886.132	Cr	00	4900.455		0000
4886.268		0000	4900.648		0000
4886.359		0000	4900.808		000
4886.522	Fe	3	4901.002		00
4886.757		0000	4901.152	Ti	0
4886.899		000	4901.498		0000 N
4887.027		0000	4901.793		000 N
4887.187	Ni, Cr	2	4902.028		000 N
4887.381	Fe?	2	4902.257		0000
4887.549		00	4902.416		000
4887.715		0000	4902.562		000
4887.879		000	4903.278		0000
4888.344		000	4903.440 } s	Cr	0
4888.706	Cr	00	4903.502 } s	Fe	5

ON THE ELECTROMAGNETIC NATURE OF THE SOLAR RADIATION AND ON A NEW DETERMINATION OF THE TEMPERATURE OF THE SUN.

By H. EBERT.

A NEW method of determining the temperature of those regions in the Sun which emit the continuous spectrum has become possible, since the investigations of Langley and Rubens have revealed the existence of a definite relation between the wave-length of the maximum point of the energy curve and the absolute temperature of the radiating body. Langley, by means of a rock-salt prism, investigated the distribution of energy in the spectrum of a body which was coated with lampblack and heated to a definite temperature, and found that the minimum deviation of the maximum ordinate of the curve increased with the temperature. To the investigations of Rubens we are indebted for an exact knowledge of the dispersion of rock-salt far down into the infra-red. With the aid of the data supplied by Langley's researches, Rubens succeeded in deducing the law that the wave-length λ of the maximum energy is inversely proportional to the square root of the absolute temperature T of the radiating body. From observations of the radiation of blackened bodies between absolute temperatures varying from 373° to 1088°, he found the relation:[1]

$$\lambda\sqrt{T} = 123,$$

λ being expressed in microns ($\mu = 0.001$ millimeter).

In the continuous background of the solar spectrum the maximum energy is in the orange, or, more definitely, according to the careful measurements of Langley, very nearly at 0.6μ. There remains only the question, whether we can regard the incandescent particles in the Sun, which yield the continuous spectrum, as comparable to a black body with respect to their total radiating capacity.

[1] *Wied. Ann.* **53**, 284, 1894.

The early discussions of this subject by Zöllner, and the experiments of Wüllner on the spectra of compressed gases, showed that in the case of the Sun, even if a gaseous constitution were assumed, and no matter what solar theory were adopted, the emission would extend over a great range of wave-lengths, in consequence of the high pressure which must be regarded as existing there. This conclusion has been verified by later investigations, although views as to the nature of radiation have undergone considerable change. A comparison of the form of the solar energy curve with that of a strongly damped electric oscillator shows that in sunlight we are dealing with electromagnetic vibrations, originating principally in small electric oscillators, the fundamental period of which is that of the red hydrogen line $H\alpha$ (Garbasso). It has been shown by F. Richarz, and later by Ebert, that the electric valence charges of the atoms, which with Faraday we must suppose to exist in order to account for the phenomena of electrolysis, afford by their vibrations a satisfactory explanation of radiation by a self-luminous body. The fact that hydrogen is one of the most important constituents of the Sun points, from an entirely new direction and in harmony with all other teachings of solar physics, to the same conclusion. According to the curve of emission, however, the electrical oscillations of the valence charges of this gas extend over a great range of wave-lengths; this fact is indicative of strong damping, and hence, according to the interference experiments of Ebert, of frequent collisions between similar molecules, *i. e.*, great density. The hydrogen to which the continuous background of the solar spectrum is mainly due must therefore be in a strongly compressed state, and this consequence also is in accord with all solar theories. The above-mentioned state of the electrically charged hydrogen atoms which mainly determine the solar radiation, and which, for the most part, must therefore execute forced vibrations, imposes the condition that incident electromagnetic vibrations of very different wave-lengths must be reinforced, and that their energy must be changed into other forms, and especially into heat (experiments of P. Lebedew on electromagnetic

radiation). The last result may be expressed thus: Rays of very different periods, such as are emitted by the oscillators which are essentially the source of solar radiation, are also absorbed by them. With respect to electromagnetic radiation, the principal mass of the Sun acts like a black body. As we find in a solar spectrum a great range of emitted wave-lengths, we may also conclude that for these wave-lengths the radiating body exercises a very complete absorption.

We might have arrived at the same result by the application of Kirchhoff's law, according to which there must be a corresponding absorption where there is emission. But it is very doubtful whether the law can be applied to the Sun, or to self-luminous heavenly bodies in general, since in this case we are hardly dealing with the "normal" distribution of energy among translatory, rotary and oscillatory motions, for which alone, as E. Wiedemann has proved, the law is valid. The luminous action taking place on the Sun is, like that in a Geissler tube, rather to be counted among the phenomena of "luminescence," in which the excitement of the atomic charges and therefore the radiation are far more intense than those which would correspond to translatory motion (*i. e.*, temperature) under normal conditions.

If then we take our stand upon the ground that these views as to the electromagnetic nature of the solar radiation are correct, we see, as before, that the application of Rubens' formula to the parts of the Sun that give the continuous spectrum is unexceptionable, and in accordance with all recent investigations on electromagnetic radiation. Substituting Langley's value $\lambda = 0.6\mu$, the resulting temperature in round numbers is 40,000° Centigrade.

The parts of the Sun to which this value applies belong to the more interior regions; they are at any rate deep under the "reversing layer" and therefore probably below the photosphere. For these parts the temperature determined above is to be regarded as a very plausible one, and it is in good agreement with values previously determined by totally different methods.

K. Universitaet,
Kiel.

PHOTOGRAPHS OF THE MILKY WAY NEAR 15 MONOCEROS AND NEAR ϵ CYGNI.

By E. E. BARNARD.

I SEND two more photographs for reproduction in THE ASTROPHYSICAL JOURNAL (see AP. J. No. 1).

These were also made with the Willard six-inch portrait lens.

THE REGION NEAR 15 MONOCEROS.

The picture near 15 Monoceros shows that star to be not only nebulous (and this is questioned in the nebula catalogues) but it shows that a vast diffused nebulosity extends for several degrees in all directions from 15 Monoceros. It extends northward for 2° or 3° to the edge of the great vacancy shown among the stars in the northern part of the picture. On the original negative this nebulosity does not condense at 15 Monoceros or any of the bright stars, but there is a strong condensation some 10′–15′ south preceding 15 Monoceros. Some 2° or 3° to the west of this will be seen an irregular elliptical nebulosity that involves several considerable stars.

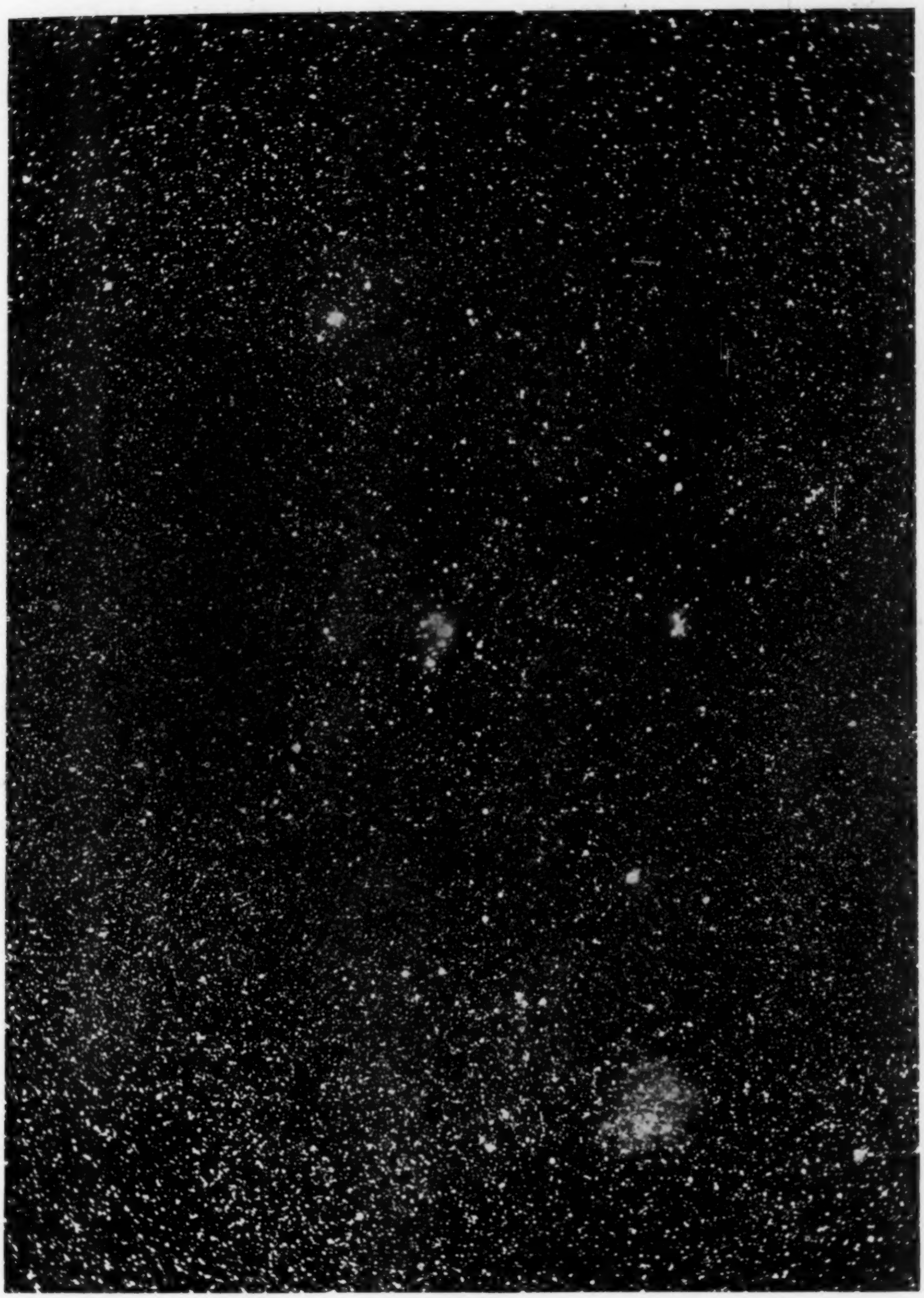
This nebula was found by me in 1888 with the twelve-inch. The photograph shows several peculiar, sharply defined black holes or perforations in the north part of it. The telescopic view gives one no idea of the form of this object, and nothing can be seen of the dark holes in it. Indeed, the entire object is extremely difficult in any telescope. Its position for 1860.0 is R. A. 6^h 23^m 27^s; Dec. N. 10° 7′.

In the southern part of this picture is shown a mixture of stars and nebulosity, an enlarged photograph of which was printed in *Astronomy and Astro-Physics*, No. 138. The nebula was discovered by Swift, about 1857, but was not recognized as a new nebula until 1883, when I independently found it. This object is N. G. C. 2237 and its position for 1860.0 is R. A. 6^h 23^m 29^s; Dec. N. 5° 2′.5.

PLATE III

N

E



W

S

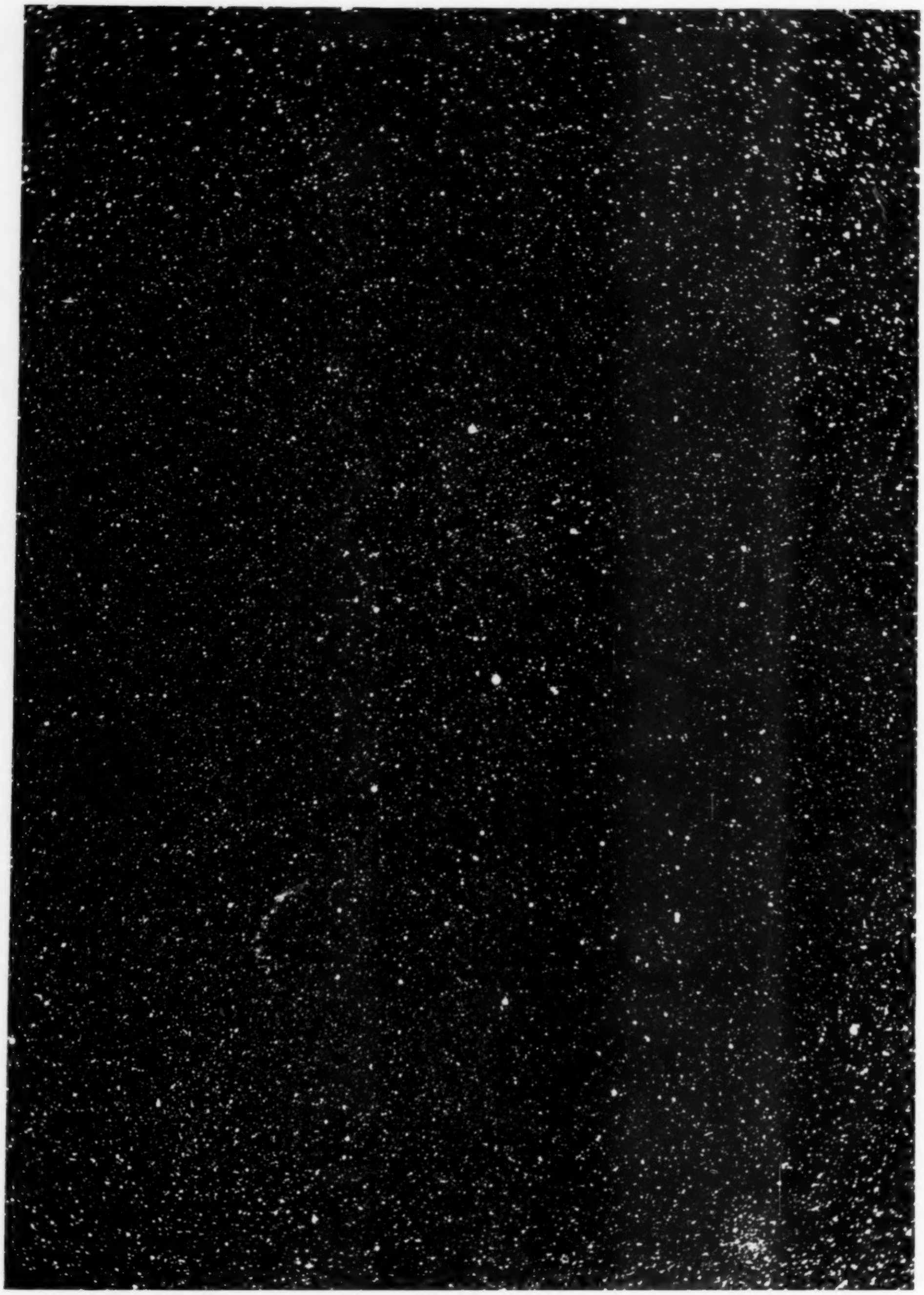
PHOTOGRAPH OF THE MILKY WAY NEAR 15 MONOCEROS

By E. E. Barnard, Lick Observatory

Exposure 3^h 0^m — Feb. 1, 1894 — Six-inch Portrait Lens

N

E



W

S

PHOTOGRAPH OF THE MILKY WAY NEAR ϵ CYGNI

By E. E. BARNARD, Lick Observatory

Exposure $5^h\ 20^m$ Sept. 25, 1894 Six-inch Portrait Lens

THE REGION OF ε CYGNI.

This photograph shows the Milky Way about the star ε Cygni. South of ε Cygni will be seen two or three very singular, long nebulous strips. One of these passes through the star κ Cygni. This is N. G. C. 6960, and its position for 1860.0 is R. A. 20^h 39^m 53^s; Dec. N. 30° 12′.8. It is extremely narrow and runs north and south for over a degree. It will be seen that this nebula is very sharply pointed at its north end and at its south end becomes somewhat broader and shredded. The picture shows that it passes close following κ Cygni, and that its apparent connection with that star is probably a case of accidental projection.

Following this is the knotted and curved nebula N. G. C. 6995 whose place for 1860.0 is R. A. 20^h 51^m 20^s; Dec. N. 30° 40′.7. It will be seen that this remarkable nebula is made up of a curve of nebulous clouds. This is an easy object in a telescope and the cloud-masses are striking to the eye.

Between these two nebulæ, and a little north, is a fainter and irregular mass of nebulosity. The bright star in the middle of the picture is ε Cygni.

MT. HAMILTON, May 22, 1895.

ON THE LIMIT OF VISIBILITY OF FINE LINES IN A TELESCOPE.

By ALBERT A. MICHELSON.

IT is well known that the *limit of resolution* of a telescope is given by the expression

$$e_o = \frac{\lambda}{a},$$

in which λ is the wave-length of the light employed and a, the diameter of the object-glass. The expression may be translated to mean that it would be difficult to perceive as separate objects two points or lines whose distance subtends an angle less than e_o.

But it does not at all follow that lines or other objects of smaller apparent magnitude than this would be invisible. This would depend, however, on the brightness a of the object as compared with that of the background b upon which it is projected. The expression for the intensity of the image of a line of angular width $d\xi$ in a telescope provided with a rectangular aperture is

$$dI = a \frac{\sin^2 \kappa (x - \xi)}{\kappa^2 (x - \xi)^2} d\xi,$$

in which $\kappa = \frac{\pi}{e_o}$ and x is the angular distance from the axis.[1]

The intensity due to a band of breadth e, and of constant brightness a, that of the rest of the field being b, would be

$$I = 2b \int_0^\infty \frac{\sin^2 \kappa (x - \xi)}{\kappa^2 (x - \xi)^2} d\xi - 2(b - a) \int_0^{\frac{1}{2}e} \frac{\sin^2 \kappa (x - \xi)}{\kappa^2 (x - \xi)^2} d\xi.$$

[1] See Lord Rayleigh's article, "Wave Theory," *Ency. Brit.* The expression for a circular aperture is there worked out, but the results differ so slightly from those here given that for the present purpose the simpler expression will answer.

The first integral is $\frac{\pi}{2\kappa}$. The second may be replaced by

$$\frac{1}{2}e\frac{\sin^2 \kappa x}{\kappa^2 x^2},$$

since the limiting values of ξ are very small. We have, therefore,

$$I = \frac{\pi}{\kappa}b - (b - a)\, e\frac{\sin^2 \kappa x}{\kappa^2 x^2}.$$

On the axis $I_o = \frac{\pi}{\kappa}b - (b - a)e$, while at a sufficient distance

$$I_1 = \frac{\pi}{\kappa}b.$$

Accordingly we have

$$\frac{I_1 - I_o}{I_1} = \frac{b - a}{b} \cdot \frac{e}{e_o}.$$

If $r = \frac{I_1 - I_o}{I_1}$ and $\rho = \frac{b - a}{b}$

$$\frac{r}{\rho} = \frac{e}{e_o}.$$

That is, the ratio of the percentage excess of brightness of image to that of object is equal to the ratio of angular magnitude of the object to the limit of resolution of the telescope.

To find the limit of visibility in the case of a fine wire stretched against a bright background, let $r = .02$ be the limit of percentage difference in brightness readily perceptible to the eye. For this value, and on the supposition that no light reaches the eye from the wire itself, we have

$$e = .02\, e_o,$$

from which it appears that a line subtending an angle only one-fiftieth of the limit of resolution may still be distinctly seen.

To test the value of this deduction, a platinum wire $0^{cm}.01$ diameter was stretched across a window-frame, the background being a nearly uniform gray sky.

This was observed through various apertures and at such distances that the wire was just visible. The following is a table of results:

Width of Aperture	Form	Limiting Distance	$\frac{e}{e_0}$
cm		cm	
0.12	circle	550	.033
0.16	circle	1100	.022
0.08	slit	460	.035
0.15	slit	1000	.030
0.10	circle	1400	.012
			Mean = .026

The last result was obtained under better conditions than the others, in consequence of the distance being fixed while a series of circular apertures of gradually diminishing size were placed in quick succession in front of the eye. The naked-eye experiments proved somewhat better than those made with a telescope, on account of the greater uniformity of the field.

It appears, therefore, that the theoretical result is amply confirmed by experiment.[1]

An interesting application of these results is suggested in the problem of the "canals" of Mars. I am not aware that these markings have been satisfactorily observed with an objective of less than eighteen inches aperture. If this be taken as the limiting aperture, the above formula would give $e = 2 \times 10^{-8}$ as the smallest angular width which could be distinctly observed. Taking the distance of Mars under favorable conditions at fifty million miles, this would correspond to an actual width of the canals of about one mile.

This supposes, however, that the canals are quite dark. Otherwise this result would have to be multiplied by the ratio

$$\frac{a}{b-a}.$$

[1] Evidently the case of a bright line upon a dark background is also covered by the formula, and since in this case there is practically no limit to the value of ρ, the ratio $\frac{e}{e_0}$ may be very small indeed, as is indeed at once evident in the case of the fixed stars, or that of a spider-web reflecting sunlight.

CONDITIONS AFFECTING THE FORM OF LINES IN THE SPECTRUM OF SATURN.

By JAMES E. KEELER.

IN a previous article[1] I described a spectroscopic proof of the meteoric constitution of Saturn's rings, and determined the form of the equations to the spectral lines when the slit of a spectroscope is made to coincide with the major axis of the ring on the slit plate. A number of photographs which I have recently obtained under different conditions show that it is desirable to consider a somewhat more general case than that above mentioned, so that the effect of instrumental displacements can be ascertained. It is obviously impossible to keep the image perfectly motionless on the slit plate during the long exposure which is made necessary by the faintness of the object and the high dispersion of the spectroscope, and errors in guiding affect the characteristic forms of the lines.

It is not however necessary to consider the most general case of the slit in any position angle. The slit can be placed quite accurately parallel to the major axis of the ring, either by direct observation with a diagonal eyepiece, such as is now used on nearly all elaborate astronomical spectroscopes, or by setting the position circle of the instrument with the aid of an ephemeris, while the effect of any slight departure from this position is easily seen to be very small. It will be sufficient to consider the case where the slit is parallel to the major axis of the ring, but not necessarily coincident with it. The effect of any displacement across the line of the slit can then be determined from the equations to the spectral lines, while the effect of drift along the slit, being merely to shift the whole spectrum in the direction of its breadth, can be seen at once when the former effect is known.

As in the special case first considered, the collimator and

[1] See this JOURNAL, 1, 416.

camera are supposed to have the same focal length, so that the point x, y of the spectral line corresponds to the point x of the slit. The symbols below have very nearly the same meaning as in my former article.

Let x, y be the coördinates of a point on the displaced line, referred to the same axes as before,

v = velocity in the line of sight of point on Saturn corresponding to x,

α = Saturnian longitude of the same point, reckoned from the central meridian,

γ = Saturnian latitude of the same point,

V' = velocity of a point on the equator of Saturn,

2ρ = diameter of the image of the ball on the slit plate,

β = elevation of Earth above the plane of the ring.

To determine the form of a line in the spectrum of the planet we have

$$x = \rho \sin \alpha \cos \gamma,$$
$$y = av = aV' \sin \alpha \cos \beta \cos \gamma,$$
$$\frac{y}{x} = \frac{aV'}{\rho} \cos \beta = \text{constant}.$$

The inclination of the line, being independent of γ, is therefore the same for all parts of the disk. If the image is displaced in declination[1] the only effect will be to give a disproportionate exposure to the middle parts of the lines, as the spectrum will not then be wide enough to reach their ends. The effect of drift in right ascension[1] will be to broaden the lines equally throughout their length. This peculiarity of the spectrum of a rotating sphere has been pointed out by Deslandres.[2]

To determine the form of a line in the spectrum of the ring, regarded as a swarm of particles moving in circular orbits, the following additional symbols are required :

Let n = ratio of size of object to size of image on the slit plate,

nR = radius of the orbit of a particle corresponding to the point x,

[1] For convenience I use motion in right ascension and declination to signify respectively motion in the direction of the slit and at right angles to it.

[2] *C. R.* **120**, 417.

$V =$ orbital velocity of the same particle,

$q =$ distance of the slit from the major axis of the image of the ring,

$p =$ projection of this distance on the plane of the ring, so that $q = p \sin \beta$.

Then the motion of x in the line of sight is

$$v = V \sin \alpha \cos \beta,$$

and by Kepler's third law,

$$V = \frac{k'}{R^{\frac{1}{2}}};$$

hence

$$v = \frac{k'}{R^{\frac{1}{2}}} \sin \alpha \cos \beta.$$

By the geometrical relations of the quantities,

$$R = (p^2 + x^2)^{\frac{1}{2}}; \ \sin \alpha = \frac{x}{(p^2 + x^2)^{\frac{1}{2}}}.$$

Substituting these values,

$$y = av = \frac{ak' x \cos \beta}{(p^2 + x^2)^{\frac{3}{4}}},$$

and placing the product of the constant terms equal to k, we have, for the equation to a spectral line,

$$y = \frac{kx}{(p^2 + x^2)^{\frac{3}{4}}}.$$

This reduces to the form $y = kx^{-\frac{1}{2}}$ for the special case considered in my former article, when $p = 0$.

The general equation to the family of curves obtained by giving different values to p is

$$\frac{y}{x} - \frac{dy}{dx} - \frac{3y^{\frac{7}{3}}}{2k^{\frac{4}{3}}\, x^{\frac{1}{3}}} = 0.$$

In what follows I have considered only such properties of these curves as have a physical bearing on the present subject. The direction of a spectral line at any point is given by

$$\frac{dy}{dx} = \frac{k\left(p^2 - \frac{x^2}{2}\right)}{(p^2 + x^2)^{\frac{7}{4}}}.$$

At the origin, $\tan \phi = kp^{-\frac{3}{2}}$.

The maximum ordinate of the curve, at $x = p\sqrt{2}$, is

$$\frac{2^{\frac{1}{2}}k}{3^{\frac{3}{4}}p^{\frac{1}{4}}} = 0.620kp^{-\frac{1}{4}} .$$

The variation of the inclination of a line produced by a displacement dq of the slit is

$$\frac{d}{dp}\left(\frac{dy}{dx}\right)\left(\frac{dp}{dq}\right) = \frac{3kp\,(5x^2 - 2p^2)}{4(p^2 + x^2)^{\frac{7}{2}} \sin\beta} .$$

It is small when p is small and x large, but when x is small the change may be very great. The latter case cannot, of course, occur in practice. The ring is limited in breadth, while the equations refer to particles in a plane extending indefinitely outward from a point in which the entire mass of the planet is concentrated.

By means of these equations I have traced the curves shown in Fig. 1, by which the effect of a change in the declination of the slit, or in its width, is more readily seen than by the formulæ. The six curves shown correspond to values of p respectively equal to 0, $\frac{1}{20}$, $\frac{1}{10}$, $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{7}{10}$ of the radius of the outer ring, or to values of q equal to the same fractions of the semi-axis minor of the apparent ellipse.[1] The unbroken parts of the curves correspond to actual points in the system. It will be seen that scarcely any effect on the position or direction of a line in the spectrum of the ansa is produced by a displacement in declination not exceeding one-fourth the semi-axis minor, and a displacement greater than this would mean very poor guiding. At half the semi-axis minor the effect on the line is very considerable, but at this point the spectrum of the ring begins to encroach on that of the planet, and the two spectra would not be sharply separated on the photograph. The separation of the photographed spectra is in fact a good test of the guiding during the exposure.

The effect of a displacement in right ascension is found as before, by allowing the line corresponding to a given value of p

[1] The constant k, *i. e.*, the scale of the ordinates, is so chosen that the inclinations of the lines are not greatly exaggerated, as compared with an actual photograph taken with a powerful instrument. The implied dispersion is about three times that of my own instrument in the yellow, or nearly the same as that of my instrument in the violet.

PLATE V

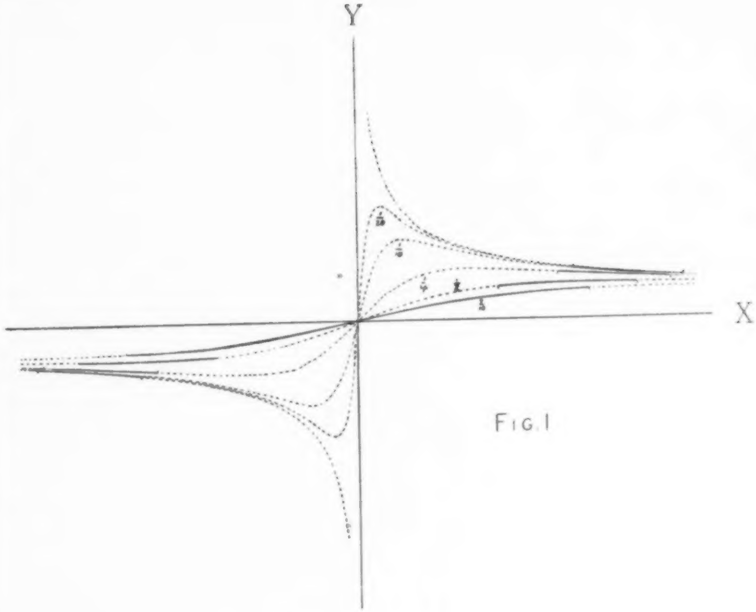


FIG. 1

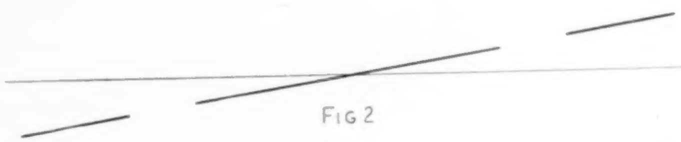


FIG 2

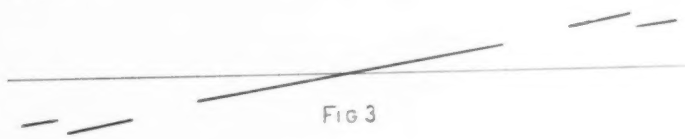


FIG 3

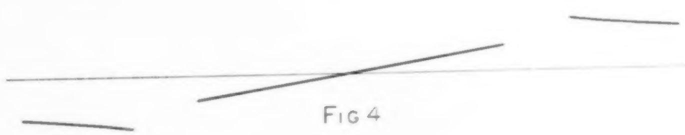


FIG 4

to move, as a whole, parallel to the axis of x. If the displacement is so great as to amount to more than the whole width of the ansa, a widened line or band will be produced, parallel to an undisplaced line in the spectrum; but the inclination of the line is so small that no very detrimental effect will be produced on the definition. It will be observed that in every case displacements tend to make the lines in the spectra of the ansæ parallel to the undisplaced lines of the solar or other comparison spectrum. This result is entirely in accordance with my experience. I have always found that with imperfect guiding or an unsteady atmosphere the characteristic reversed inclination of the lines in the spectra of the ansæ, which is the proof of the meteoric constitution of the ring, is lost, although the definition of the lines may be very fair.

The effect of widening the slit can also be readily found by means of the curves in Fig. 1. If the brightness of the ring could be expressed as a continuous function of its radius it would be possible, by integration between limits, to determine the width, density, etc., of a photographed line in the spectrum for any position and width of the slit, although the results would hardly repay the labor.

There is one position of the slit for which the curve in the vicinity of the origin represents a real spectral line. If $p = 0.7$ of the radius of the outer ring, or $q = 0.7$ of the semi-axis minor of the ellipse, the slit will fall entirely on the ring where it crosses in front of the planet. The photographed spectral lines would then have a point of inflexion at the center; they would form a sharp contrast with the lines that would be obtained if the ring was solid, and a still sharper contrast with lines due to two solid rings having different periods of rotation. The curve for this position of the slit is represented by the innermost curve of Fig. 1. With careful guiding I think there would be no difficulty in making the very interesting experiment of photographing the spectrum of this part of the ring, but a reflecting slit would probably be required, like that devised by Dr. Huggins, as the whole image would have to be visible in the guiding eyepiece.

We now apply the more general case to the ring regarded as a solid body. As before,

$$y = av = aV \sin \alpha \cos \beta,$$

and

$$x = R \sin \alpha.$$

Hence,

$$\frac{y}{x} = a \frac{V}{R} \cos \beta.$$

For a solid ring $\frac{V}{R}$ is constant. The inclination of the line is therefore independent of the position of the slit, and the same remarks apply to the effect of instrumental displacements as in the case of a rotating sphere.

In Figs. 2, 3, and 4, which are drawn to the same scale as Fig. 1, I have represented the form of a line in the spectrum of the system of Saturn, when $p = 0$, according to three different hypotheses as to the constitution of the rings. In Fig. 2 the ring is supposed to be single; in Fig. 3 it is supposed to consist of two independent rings separated by the Cassini division (the structure assumed by Laplace), and in Fig. 4 it is regarded as made up of independent small bodies, this figure being the same as that of my former article. As I have there shown, a photograph of the spectrum with accurate guiding decides at once in favor of the last hypothesis. A less satisfactory test could also be obtained, even if the image wandered irregularly on the slit plate; for, according to the preceding investigation, the effect of displacements would be different in each of the three cases. In the case illustrated by Fig. 2 the definition of lines in the spectra of the ansæ and the ball would be the same; in the case of Fig. 3 the lines in the spectra of the ansæ would be very badly defined as compared with those of the ball, and in the case of Fig. 4 they would be better defined than the lines of the ball. It is hardly necessary to say that the geometrical sharpness of the lines in the figures is not to be expected under any circumstances in the case of a photograph, and the effect of displacement of the image is to produce a general blurring of the lines, the cause of which, on account of the indefiniteness of the image, could not be ascertained by simple inspection of the plate.

Minor Contributions and Notes.

NOTICE.

Attention is called to the fact that The Astrophysical Journal is not issued in July or September. The next number will be published August 1.

NOTES ON SCHMIDT'S THEORY OF THE SUN.

An objection which might be raised against Schmidt's theory of the Sun occurred to me some time ago, but I have found a very reasonable way of meeting it.

I said in my paper (see the February number of this Journal, p. 112) that I considered the assumption of a shallow reversing layer a very artificial one, and that Schmidt's theory had the advantage of not requiring it. But the observations made by Young and others during total eclipses seem to prove the existence of this layer. It is asserted by these observers that suddenly the whole spectrum is reversed, the arrangement of the bright lines being precisely the same as that of the dark lines a moment before. If these observations be accepted as conclusive, our theory encounters a serious difficulty. For it would follow that the white light of the Sun must have its origin at the apparent solar limb, since we cannot reasonably assume that all of the absorption takes place at this height, and none below.

But let us remember that we are led by various considerations to conclude that at this altitude the solar atmosphere is very rare, and that we also know hydrogen, sodium, magnesium, iron, etc., to be present in the chromosphere. Now, the atomic weight of iron is 56, and, according to Scheiner's *Spectralanalyse der Gestirne*, the atomic weights of all elements whose presence in the Sun has been definitely proved are less than 60 (lead excepted). I do not here include those elements which Lockyer affirms to be present (lead, cadmium, etc.); these (excepting lead) have atomic weights smaller than 120. Moreover, I believe that all or most of the *characteristic* lines of the solar spectrum have been identified with those of terrestrial substances. If this is so we see that the characteristic part of the solar spectrum is produced by elements

of small atomic weight, or, if we assume the elements to be, in general, arranged according to their atomic weights, by a certain comparatively narrow stratum of the gaseous body of the Sun. This need not, however, be as narrow as the "reversing layer" in the ordinary sense of the word. If in the usual theories the reversing layer has a depth AB, there is nothing to hinder the advocate of Schmidt's theory from assuming AB to be only the upper portion of a much deeper layer AC, in which these metallic vapors are found intermingled, though in general distributed in the order of their atomic weights. We may consider this layer to be as deep as the zone which sends no tangential rays to the observers. If it were still deeper the "reversing layer" in the ordinary sense of the word would seem to be higher than it is. Below this layer the heavier metals would be found. But as it has already been shown that this may be at a considerable depth it is possible that at this level the pressure is so great that these metals give a continuous spectrum. This would account for the fact that so few heavy metals have been found in the Sun. In the lower layers, however, the lines would be widened. This last fact obviously sets a limit to the depth which we can assume for such a reversing layer, for observation shows that most of the Fraunhofer lines are fairly sharp. The heavy metals, however, so far as they are present, ought to give widened lines. I do not know how far observation confirms this consequence of our theory. Possibly the bands in the spectrum of stars of Vogel's type III are due to this circumstance; this idea would seem to be confirmed by the fact that these stars are reddish, since this indicates that the ray has traversed a thick atmosphere.

Viewed in this connection, the fact that in eclipses the solar spectrum seems to be reversed for a few seconds can easily be explained. The layer containing the metals of small atomic weight produces the characteristic features of the spectrum, and on these rare occasions of total eclipse its upper portion is seen directly, without the continuous spectrum. If this view of the matter is correct the lines of the heavy metals ought not to be reversed; unless, indeed, the small amounts of these metals accidentally present at this elevation should be sufficient to show characteristic spectra.

It has been suggested to me by Professor Scheiner that if Schmidt's theory be true the absorption lines in the solar spectrum ought to appear very much broadened. For the theory assumes that the white

light has its origin at a certain depth below the apparent surface of the Sun, and that it is caused by the great pressure of the overlying strata. As we ascend from this depth we should find the continuous spectrum gradually changing into broad bands and finally into narrow lines. On account of the increased absorption the intensity of the bands should increase with the elevation, and the lines should therefore appear broad, and have no definite boundary.

The essential supposition in the above argument is that one and the same substance is found in all the successive strata, from the lowest to the highest. But is this the case? As has already been remarked, many appearances seem to indicate that the Sun is stratified into layers in which the elements are arranged according to their atomic (or molecular) weights. Of course the boundaries of the layers cannot be well defined; in these regions there must be a more or less complete mixture. On this supposition the above objection to Schmidt's theory disappears. For let us suppose the Fraunhofer lines to originate in a region where the pressure is not great enough to widen them appreciably; it is evident that they should belong to the lighter metals, such as sodium, magnesium, etc. (including iron). The heavier metals will be found lower, and owing to the great pressure their lines should be very broad. As they are nearer the center of the Sun than the lighter elements, the darkest part of their absorption bands should be much brighter than the narrow absorption lines of these lighter substances. The widened absorption lines should therefore appear simply as a less brilliant portion of the continuous spectrum. The theory thus indicates that the continuous background of the solar spectrum should show differences in brightness. I believe this is in accord with observation. If so, we have a new support for the theory. For differences in the intensity of the continuous spectrum would be difficult to explain by the ordinary theories of the constitution of the Sun. The density of the atmosphere above the photosphere is too small for any such action as that outlined above to take place; and to explain such an appearance as due to groups of lines too close together to be separately seen seems to be insufficient, on account of the great extent of the regions which, I believe, these appearances occupy.

Still another objection to the theory is frequently made. It is stated that if the apparently sharp boundary of the Sun is the result of refraction it would necessarily follow that the Sun must be in a very quiet condition. Let us examine this point a little more closely. If any-

where along the path of the light there is a disturbance its only influence upon the ray will result from a change of the index of refraction μ by $d\mu$. The consequence of this will be a change in a by da. We have

$$\mu r \sin a = \mu_2 r_2;$$

hence

$$\frac{da}{d\mu} = -\frac{1}{\mu} \tan a.$$

In a body of the second class we never have $a = \frac{\pi}{2}$ in the regions we are considering; for we are not concerned with the lower spheres because the absorption will prevent their light reaching us. For the critical sphere a will, however, $= \frac{\pi}{2}$, and consequently $\tan a = \infty$, but this ray cannot enter our eyes. For the neighboring spheres $\tan a$ will be large. But as we have already mentioned, it is well known that the density of the gases at this altitude is extremely small, so that μ will not differ appreciably from 1. Thus in the higher regions a considerable disturbance can have no appreciable effect on the value of μ, because it is approximately equal to unity. We can therefore put $d\mu = 0$, and hence conclude that $da = 0$, *i. e.*, the direction of the ray cannot be changed by an appreciable amount. Consequently the remaining path of the ray will be unchanged, and likewise the value of r_2, the apparent semi-diameter of the Sun. So far only the higher regions have been considered, but it is obvious that where the value of μ differs considerably from 1 the density and pressure are so great that the spectrum of those regions must consist of greatly widened lines. Consequently the light from the spheres below a certain limit will not reach the eye. In the spheres above this limit $\frac{d\mu}{\mu}$ must always be a very small fraction, usually quite inappreciable. Hence da must always be very small, and the above conclusion holds good.

These are the only real arguments I have heard against Schmidt's theory of the Sun, and it does not seem difficult to answer them. Of course I have advanced no *proof* of the theory, but I think enough has been said to show that it is well worth following out in its consequences. If we knew the critical temperature of the metallic vapors constituting the Sun, and the temperature of the Sun itself, it would of course be possible to decide at once which theory is correct. I think there must be bodies of both kinds in the universe; some too hot to contain con-

densed materials, to which our theory would apply, and others containing condensed matter in the form of a real photosphere. I believe it is too early to decide to which class our Sun belongs.

E. J. WILCZYNSKI.

The above extracts from two letters received from Mr. Wilczynski are of interest in suggesting certain criteria by which Schmidt's theory of the Sun may be tested. In the first place it should be pointed out that the investigations of Rowland have added many elements of high atomic weight to the list of those known to be present in the Sun. At least eighteen elements of atomic weight higher than 60 are certainly represented in the solar spectrum, and there is doubtful evidence of the presence of several others. Among the established cases may be mentioned those of rhodium (104), palladium (106), silver (108), cadmium (112), tin (119), barium (136), lanthanum (138), cerium (140), neodymium (145), erbium (166), and lead (206).[1] It is true that when the elements found in the Sun are grouped in the order of the intensity of lines in the solar spectrum the heavier elements are almost altogether confined to the second half of the list, but among them are carbon (12), scandium (44), and niobium (59), with potassium (39) at the foot of the column.[1] In Rowland's wave-length tables, which so far as published cover only a portion of the upper spectrum, there is at least one lanthanum line of intensity 12, and a barium line of intensity 8. On the other hand, it might be urged that the heavier elements have comparatively few lines in the solar spectrum. Of some of them this is true, but in Professor Rowland's list of the solar elements arranged according to the number of lines present in the solar spectrum we find zirconium (90) ninth and cerium (140) tenth, each with over 75 lines to its credit, neodymium (145) thirteenth, lanthanum (138) fourteenth, with such metals as magnesium (24), sodium (23) and aluminium (27) far below them.[1]

It is of course evident that the value of such comparisons as these must be lessened by the fact that the spectra of the elements are not all built upon a single type, but vary greatly both in the number and the intensity of the lines. There is also the further difficulty that the stratification of the solar atmosphere must be continually disturbed by the violent down and up rushes from which it is never free. Thus some of the heavier metallic vapors, which according to Schmidt's

[1] *Johns Hopkins University Circulars*, February, 1891.

theory ordinarily exist at a low level, must rise toward the surface, where they can make their presence visible in the spectrum. If this be put forward by the supporters of Schmidt's theory as an explanation of the presence in the solar spectrum of so large a number of lines due to the heavier elements, the objection raised by Professor Scheiner, and quoted by Mr. Wilczynski, would seem to be sustained. For if a single element were present at widely different levels, and hence, on the assumption of the theory, under conditions of temperature and pressure ranging from those compatible with the production of narrow spectral lines to those under which the element in question must give a continuous spectrum, it would follow that such an element could have no narrow and well-defined lines in the solar spectrum. As a matter of fact Rowland's tables contain numerous sharp and narrow lines of cerium, lanthanum, neodymium and other heavy metals. A few instances taken at random include cerium lines a λ 4127.529, λ 4142.562 and λ 4145.152 of intensities 00, 00 and 0 respectively; lanthanum lines at λ 3794.909 (1), λ 4141.809 (0), λ 4196.699 (2), λ 4204.163 (4) an extremely sharp line, and λ 4123.384 (12) according to Rowland one of the strongest lines in the lanthanum spectrum; neodymium lines at λ 3911.316 (0), λ 4156.238 (0) very sharp, and λ 4177.495 (0); and a very sharp barium line of intensity 2 at λ 4130.804. Thus, instead of indicating their presence in the solar spectrum by bright spaces, these heavy metals give well-marked dark lines.

It may be added that of the fourteen elements not found by Professor Rowland in the solar spectrum six have atomic weights less than 80.[1]

It seems to me that a consideration of such facts as these will merely tend to strengthen the feeling entertained toward Schmidt's theory by most astrophysicists. As a theoretical discussion the theory is interesting and valuable, but few observers of the Sun will consider it capable of accounting for the varied phenomena encountered in their investigations. G. E. H.

NOTE ON THE YERKES OBSERVATORY.

The frontispiece is a photographic reproduction of a water-color sketch showing the Yerkes Observatory as it will appear when completed. The construction of the building at Lake Geneva is now

[1] *L. c.* p. 42.

advancing rapidly, and it is hoped that the 40-inch telescope will be ready for use in September or October.

The form of the building is that of a Roman cross, with three domes and a meridian room at the extremities. The long axis of the cross lies east and west, with the dome for the 40-inch telescope at the western end. This dome, for which the contract has been awarded to Warner & Swasey, is 90 feet in diameter. As the tube of the 40-inch telescope is 62 feet long there will be plenty of space for a solar spectroscope 9 feet long, and a dew-cap of about equal length. The shutter-opening is 12 feet wide. Adjustable canvas curtains will be provided to shield the telescope from the wind.

Warner & Swasey have also been awarded the contract for the rising floor. It is 75 feet in diameter and will have a vertical motion of 22 feet. Both the floor and dome will be moved by electric motors.

Of the two smaller domes, the one to the northeast will contain the 12-inch telescope now at the Kenwood Observatory, and the other a 16-inch telescope. Between these domes is the heliostat room, 100 feet long by 12 feet wide. The heliostat will stand on a pier at the north end of the room, under an iron roof which can be rolled away to the south.

The meridian room has double sheet-iron walls, with an intervening air space. The room is designed to contain a meridian circle of large aperture, but for the present a transit instrument will suffice for the purposes of the Observatory.

The body of the building is divided through the center by a hallway extending from the meridian room to the great tower. On either side are offices and computing rooms, a library, lecture room, spectroscopic laboratory, optical room, dark room, developing room, galvanometer room, chemical laboratory, instrument rooms, etc. In the basement is a large photographic dark room, an enlarging room, concave grating room, emulsion room, constant-temperature room, and physical laboratory.

The building is constructed of gray Roman brick, with gray terracotta and stone trimmings. It is situated in the midst of a large tract of land on the shores of Lake Geneva, Wisconsin (about 75 miles from Chicago), at an elevation of 180 feet above the lake. The architect is Mr. Henry Ives Cobb, of Chicago.

The engines, dynamos and boilers for supplying power and heat are to be at a distance of several hundred feet from the Observatory.

In the small building that contains them will also be the shops for the construction and repair of special instruments and apparatus.

G. E. H.

ON THE PRESENCE OF HELIUM IN CLÈVEITE.

In the *Comptes Rendus* for April 16, Mr. P. F. Clève communicates to the Academy some interesting results obtained with specimens of the mineral clèveite, found at Carlshuus, Norway. When a mixture of the mineral with potassium bisulphate was heated in a combustion tube a gas was given off, which was passed over red-hot copper, and collected over a concentrated potash solution.

By comparing the spectrum of the gas with that of a tube of argon it was found that it contained no argon lines.

The following are the wave-lengths obtained by Thalén of the lines in the spectrum of the new gas. Curiously enough, some of the wave-lengths seem to refer to Ångström's and others to Rowland's scale:

Wave-length	Map	Intensity
6677.	Ångström	Moderate
5875.9	Micrometric measure	Strong
5048.	Rowland	Moderate
5016.	Rowland	Strong
4922.	Rowland	Moderate
4713.5	Ångström	Faint

The position of the second line was determined by interpolation in Rowland's table of standard wave-lengths.

Mr. Clève remarks: "It seems probable that this strong line of helium is accompanied on each side by two very faint lines." If a grating was used these may have been due to the ghosts which almost invariably accompany a very bright line.

Professor Young has pointed out in a recent letter that Thalén's lines at $\lambda 5048$, $\lambda 5016$, $\lambda 4922$ and $\lambda 4713.5$ probably coincide with chromosphere lines at $\lambda 5048.2$, $\lambda 5015.8$, $\lambda 4922.3$ and $\lambda 4713.4$ respectively.

The identification of the new line with D_3 (5875.982) may now probably be considered established, but a still more accurate measurement, or a direct comparison with the chromosphere line under high dispersion, is still to be desired.

In *Nature* for May 2, two papers communicated to the Royal Society on April 25, by Professors Ramsay and Lockyer, are printed

in full. The first describes the circumstances which led to the discovery of the new gas, and gives a qualitative comparison of the spectra in argon and helium tubes. Argon was found to be present in the helium tube, but there were sixteen easily visible lines present in the helium tube only, one of them the strong yellow line. From the fact that there were "two red lines strong in argon, and three violet lines strong in argon, but barely visible and doubtful in the helium tube," Professor Ramsay was led to suspect the presence in atmospheric argon of a gas absent from the argon found associated with helium.

Professor Lockyer's paper describes his visual and photographic observations of the gas given off by particles of Uraninite when heated in a glass tube. Most of the lines photographed appear to be due to the structure-spectrum of hydrogen, but several were obtained which are near lines in the solar chromosphere. Professor Lockyer did not find in the gas the argon and other special lines noted by Crookes, nor could he see most of the lines measured by Thalén. G. E. H.

NOTE ON THE HUGGINS METHOD OF PHOTOGRAPHING THE SOLAR CORONA WITHOUT AN ECLIPSE.

In the light of the conclusion noted last month in regard to the exposure necessary in photographing the solar corona without an eclipse I regret to find that in some of my papers I have quite unintentionally misrepresented Dr. Huggins' method of coronal photography. He has clearly pointed out from the first that what he was attempting to photograph was the increased brightness of the sky about the Sun due to the presence of the corona. The exposure required in this case is determined by the brightness of the sky and not by the brightness of the corona. Whether or not the corona will be visible in a photograph made in this way evidently depends in large degree upon the ratio of its brightness to that of the sky. G. E. H.

ON THE CAUSE OF THE GRANULATION OF THE SURFACE OF THE SUN.[1]

The views of astronomers as to the density of the gases at the surface of the Sun, *i.e.*, in the outer layers of the photosphere, differ very

[1] Translated from *A. N.* 3279.

widely, but in general the density in these regions seems to be regarded as exceedingly small. Several years ago I had already pointed out[1] that this almost inconceivable tenuity of the gases at the Sun's surface must be taken into account in framing solar theories in the future. It has not received sufficient attention in most of the theories that have been advanced hitherto, and the changes on the Sun's surface which we have had an opportunity of observing are looked upon as tremendous natural convulsions. The necessity for this view entirely disappears under the assumption of extremely small density.

It is not necessary to review here in detail the grounds on which this assumption is based; I will merely mention the narrowness of the spectral lines, and the fact that the orbital relations of comets which have passed very close to the surface of the Sun have not been perceptibly disturbed by the action of resisting forces.

Gases at a high temperature and in a state of great tenuity are in a nearly ideal condition, and hence the laws of the mechanical theory of heat can be applied to them in the widest bearings of the theory. Dr. Egon v. Oppolzer has taken advantage of this favorable circumstance, and in a very noteworthy paper[2] he has developed a theory of Sun-spots on a rigid mathematical basis, in a manner exactly corresponding to the methods of modern meteorology. Even if we should not agree with all the consequences of this theory, we must give Dr. v. Oppolzer the credit of at least showing the way by which mechanical interpretation of the phenomena in the Sun's atmosphere will lead to the desired end.

I believe now that I can take still another step in advance, by applying to the Sun the investigations of Helmholtz on waves in the terrestrial atmosphere, which have become of such fundamental importance to meteorology.

According to the theory of Helmholtz, air waves are produced when two layers of air, differing in temperature (*i.e.*, in density), glide past each other, just as waves are produced by the gliding of air over water. If the lower layer is nearly saturated with aqueous vapor, condensation will take place in the wave crests on account of the diminution of pressure. Under these circumstances the elevations or wave crests appear as clouds, the depressions or troughs as transparent inter-

[1] *Spectralanalyse der Gestirne*, p. 208.

[2] "Ueber die Ursache der Sonnenflecken." *Sitzungsber. d. Wien. Akad.* 1893.

spaces, and thus a more or less regular series of cirrus clouds is produced. If the impulses resulting in wave formation act in two different directions the waves cross, and we have the cloud effect popularly known as a mackerel sky. Helmholtz has shown that, under the assumption of temperatures of 0° and 10° for the two layers, waves of nearly a kilometer length must arise when the velocity of the air is no more than 10 meters per second, while powerful atmospheric movements produce waves up to 30 kilometers in length, which are then no longer recognized as such by their appearance, but are revealed by a periodic strengthening of the phenomenon, or gusts.

The great similarity in appearance between the solar photosphere and terrestrial cirrus has long been recognized, and there is no doubt that the necessary conditions for the application of Helmholtz's theory to the solar atmosphere — the existence of layers of different temperature, the over-saturated state of condensable gases (in the photosphere), and variously directed currents in the different layers — are found in the Sun. I therefore regard the bright grains of the photosphere as wave crests, rendered visible by condensation, or at least an increase of condensation, of two crossing systems of waves.

The increased condensation in the wave crests produces a diminution of their specific gravity, and hence their elevation tends to be greater than that required by theory alone.

It seems to me that no important objection can be urged against the explanation of the solar granulation here briefly indicated, unless the length of the waves on the Sun's surface, that is, the mean interval between the separate grains, leads to inadmissible values of the differences of temperature or of velocity. An exact computation cannot be made, as the choice of constants in the case of the Sun is too unrestricted. On the other hand it is easily seen that a very favorable value for Helmholtz's σ is probable in consequence of the high temperature, and hence waves of the required length ($1''$ to $3'' = 1000$ to 3000 kilometers) would result without the necessity of extraordinary wind velocities.

It is precisely the circumstance that the granulation is distributed over the entire surface with considerable regularity, and particularly the fact that no grains strikingly larger than the average occur (differing in size from the latter, for example, as our cirrus clouds differ from nimbus), that makes this explanation appear more probable than others which have been attempted hitherto.

I shall not trace the further consequences of my assumption at present with anything like completeness, and shall merely point out two of them. According to these views the photosphere is to be regarded as a comparatively very thin layer, its thickness being perhaps of the same order as the length of the waves formed in it, *i.e.*, a few seconds of arc; further, the velocity of the currents in the layers does not seem to differ very greatly in the different heliocentric latitudes. In this connection a more careful investigation of the average size of the grains in different latitudes would be of much interest.

J. SCHEINER.

Change of address.—The attention of contributors to THE ASTROPHYSICAL JOURNAL is called to the fact that after July 1, 1895, my address will be *Yerkes Observatory, Lake Geneva, Williams Bay P. O., Wisconsin.* All papers for publication and correspondence relating to contributions and exchanges as well as all personal communications should be sent to this address.

GEORGE E. HALE.

Reviews.

Beobachtungen angestellt am Astrophysikalischen Observatorium in O Gyalla. XV und XVI Band.

The double volume containing the results of observations made at O Gyalla in 1892 and 1893 is mainly devoted to a record of Sun-spots and to other observations of the Sun's surface. There are also observations of comets and meteors, and a few spectroscopic observations of various objects. The personnel of the observatory has lately been considerably increased.

Two new spectroscopes, recently constructed for astronomical research, are described and illustrated, but neither is of a form which can be recommended. One is a direct-vision half-prism spectroscope for visual observation, and the other a spectrograph with triple direct-vision prism. A diagonal eyepiece for viewing the slit, like that which has long been in use on many Star spectroscopes, is described as a novelty.

Ein neues Spectralphotometer. Arthur König. *Wied. Ann.* **53** (1894).

The spectrophotometer described by the author is constructed as follows: The slit of an ordinary prismatic spectroscope is covered by a plate, in which are two closely adjacent apertures; one of these is provided with a totally reflecting prism, so that two sources of light can be compared. Between the collimator and the prism of the spectroscope is a Rochon prism, so placed that a vertical separation of images is produced (the slit and the refracting edge of the prism are supposed to be vertical). Between the prism and the observing telescope is a bi-prism of glass with its refracting edges horizontal. By the combined action of the prisms eight spectra are formed in the focal plane of the observing telescope, only two of which are allowed to reach the eye, and therefore require consideration; one is formed by light coming from the upper slit, the other by light from the lower slit, and the two are polarized in planes at right angles. Further, the angles of the prisms are so chosen that the two spectra are superposed.

In the focal plane of the observing telescope is placed a diaphragm, pierced with a vertical slit, the length of which is considerably less than the width of the spectrum. An eye looking through this slit sees the objective, divided horizontally by the bi-prism into two parts, which are in general unequally illuminated. (No eyepiece is used, except for adjustment.) Finally, between this slit and the eye is placed a Nicol prism, provided with a graduated circle, by which equality of illumination can be restored, and the ratio of brightness determined by a well-known law.

With two luminous sources of equal brightness the illumination of the field is not equal, as the loss of light by reflection at the faces of the prism is different for the two sets of polarized rays; the correction is, however, easily obtained by means of the Nicol prism. The adjustments are somewhat difficult, but when once made they are not liable to be disturbed, and the performance of the instrument is very satisfactory. J. E. K.

Untersuchung der spectralen Zusammensetzung verschiedener Lichtquellen. ELSE KÖTTGEN. *Wied. Ann.* **53** (1894).

WITH the spectrophotometer of Dr. König, Fräulein Köttgen has made a study of various illuminating flames, using the flame of a triple gas-burner as a standard of comparison. The results are exhibited in the form of tables, and also by means of curves. Direct sunlight, light reflected from white clouds, and the light from a clear blue sky were also compared, the curve representing the last measurements having the most rapid ascent toward the violet. In comparing these results with those of other observers, Miss Köttgen has overlooked the elaborate investigations of Langley published in his memoir "On the Temperature of the Surface of the Moon" in Vol. III of the *Memoirs of the National Academy of Sciences.* The instrumental and other difficulties attending such comparisons are very great, and it is not surprising that the results obtained by different observers differ greatly, particularly in the upper spectrum. The author's results agree well with those of Vogel. J. E. K.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of The Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. The Sun.

Deslandres, H. Rayonnement ultra-violet de la couronne solaire, pendant l'eclipse totale du 16 avril 1893. C. R. **120**, 707–710, 1895.

Geelmuyden, H. The Solar Eclipse of 1896, August 8. Obs'y **18**, 190–193, 1895.

Lockyer, J. Norman. The Sun's Place in Nature, III, IV, V. Nat. **51**, 565–567; 590–592. **52**, 12–14, 1895.

Maunder, E. W. Notes on a Solar Photograph. Knowl. **18**, 107–110, 1895.

Rajna, M. Sull' escursione diurna della declinazione magnetica a Milano in relazione col periodo delle macchie solari. Rend. R. Ist. lombardo d. sc. e let. **28** (Ser. 2).

Riccò, A. Tentativi per fotographare la corona solare senza ecclisse. Mem. Spettr. Ital. **24**, 21–30, 1895.

Schmidt, A. Erklärung der Sonnenprotuberanzen als Wirkungen in einer hochverdünnten Atmosphäre der Sonne. Sir. **23**, 97–109, 1895.

Sidgreaves, W. The Wilsonian Theory and the Stonyhurst Drawings of Sun-spots. M. N. **55**, 282–287, 1895.

Tacchini, P. Sulla distribuzione in latitudine dei fenomeni solari osservati nel 3° e 4° trimestre 1894 al Regio Osservatorio del Collegio Romano. Mem. Spettr. Ital. **24**, 44–59, 1895.

Tacchini, P. Observations solaires des 2^e 3^e et 4^e trimestres, 1894. C. R. **120**, 710–712, 1895.

3. Stars and Stellar Photometry.

Becker, E. Bemerkungen zu dem Stern BD. $+22°.3272$. A. N. **137**, 291, 1895.

BROWN, E. and WILLIAM NOBLE. Variable Orange Stars. Obs'y **18**, 200–202, 1895.

CLERKE, A. M. Some Anomalous Sidereal Spectra. Obs'y **18**, 193–196, 1895.

CLERKE, A. M. Another Spectroscopic Binary Star. Knowl. **18**, 110–112, 1895.

SCHUR, W. Beobachtungen der veränderlichen Sterne δ Cephei η Aquilæ und β Lyræ. A. N. **137**, 297–329, 1895.

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PANNEKOCK, A. Sur le mouvement du système solaire. Bull. Astr. **12**, 193–196, 1895.

TISSERAND, F. Remarques sur les vitesses radiales des nébuleuses Bull. Astr. **12**, 196–198, 1895.

5. PLANETS, SATELLITES AND THEIR SPECTRA.

ELGER, T. Gwyn. Selenographical Notes. Obs'y **18**, 196, 1895.

KLEIN, H. J. Die neuen Mondphotographien der Pariser Sternwarte. Sir. **23**, 112–115, 1895.

MOORE, T. J. Observations of the vertical diameter of the Planet Jupiter. M. N. **55**, 306–308, 1895.

POINCARÉ, A. Sur les relations des déplacements en latitude des lignes de maxima barometrique avec les mouvements en déclinaison de la Lune. C. R. **120**, 792–794, 1895.

PUISEUX. La Lune, son état actuel et son histoire. Bull. Soc. Astr. France, May, 1895, 148–157.

THOMSON, J. P. The Transit of Mercury, 1894 November 11 ; Egress. M. N. **55**, 316–320, 1895.

WEINEK, L. Ueber die Verwerthung photographischer Mondaufnahmen. A. N. **137**, 291, 1895.

6. COMETS, METEORS AND THEIR SPECTRA.

DENNING, W. F. April Meteors. Nat. **52**, 33, 1895.

DOBERCK, W. On Heis' T Radiants. Obs'y **18**, 199, 1895.

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PERRY, JOHN. The Age of the Earth. Nat. **51**, 582–585, 1895.

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MERRITT, ERNEST. On the Absorption of Certain Crystals in the Infrared as Dependent on the Direction of the Plane of Polarization. Phys. Rev. **2**, 424–442, 1895.

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WIEDEMANN, EILHARD, und G. C. SCHMIDT. Ueber Luminescenz. Wied. Ann. **54**, 604–625, 1895.

10. THE SPECTRA OF THE ELEMENTS.

BERTHELOT. Observations sur l'argon: spectre de fluorescence. C. R. **120**, 797–801, 1895.

CROOKES, W. On the Spectra of Argon. Proc. R. S. **57**, 287–290, 1895.

GRAMONT, A. DE. Sur les spectres du sélénium et de quelques séléniures. C. R. **120**, 778–781, 1895.

HARTLEY, W. N. On the Spark Spectrum of Argon as it Appears in the Spark Spectrum of Air. Proc. R. S. **57**, 293–296, 1895.

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THIERRY, MAURICE DE. Sur un nouvel appareil dit "héma-spectroscope comparateur." C. R. **120**, 775–777, 1895.

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13. GENERAL ARTICLES, MEMOIRS AND SERIAL PUBLICATIONS.

CLÈVE, P.-F. Sur la présence de l'helium dans la clévéite. C. R. **120**. 834–835, 1895.

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RAYLEIGH, LORD, and W. RAMSAY. Argon, a New Constituent of the Atmosphere. Proc. R. S. **57**, 265–287, 1895.

NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy and position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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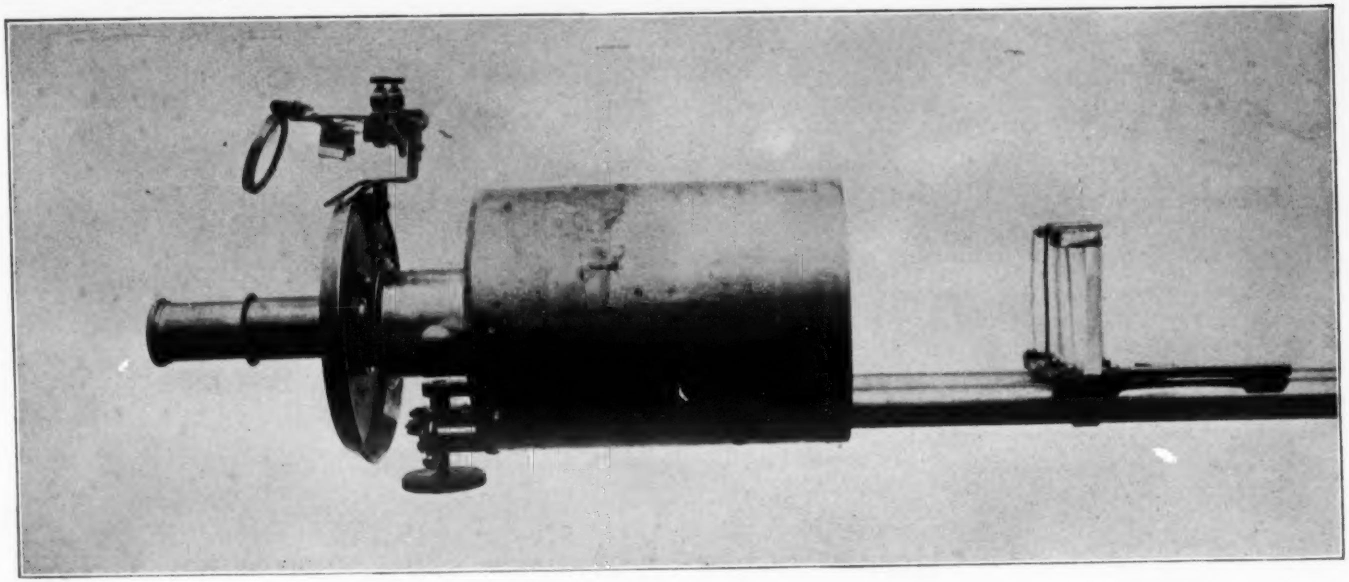
PLATE VI



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